SR 3 MP 58.21 Unnamed Tributary to Hood Canal (991240): Preliminary Hydraulic Design Report

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Y-12554 Olympic Region GEC

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ROLES AND RESPONSIBILITIES FOR THIS PHD

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form (TVF). The QC methods are defined in the Olympic Region GEC Quality Management Plan (QMP) Section 5.3 and the QMP Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), WSDOT is proposing a project to provide fish passage at the State Route (SR) 3 crossing of the Unnamed Tributary (UNT) to Hood Canal at milepost (MP) 58.21 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 991240) and has an estimated 6,014 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing and chose to use a stream simulation methodology based on the stream's relatively small size, uniform slope above and below the crossing, and confined nature of the channel's geomorphology.

The UNT to Hood Canal crossing of WDFW culvert site 991240 (project site) is located in Kitsap County, 1.1 miles northeast of Four Corners, Washington, in WRIA 15. The highway runs in a southwest-northeast direction at this location, 1,712 feet from the Puget Sound. The UNT to Hood Canal generally flows from southeast to northwest beginning 3,110 feet upstream of the SR 3 crossing (Figure 1).

The proposed project will replace the existing 99.2-foot-long, 24-inch concrete culvert with a structure designed to accommodate a minimum hydraulic opening (MHO) width of 13 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard, et al., 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT, 2022a).

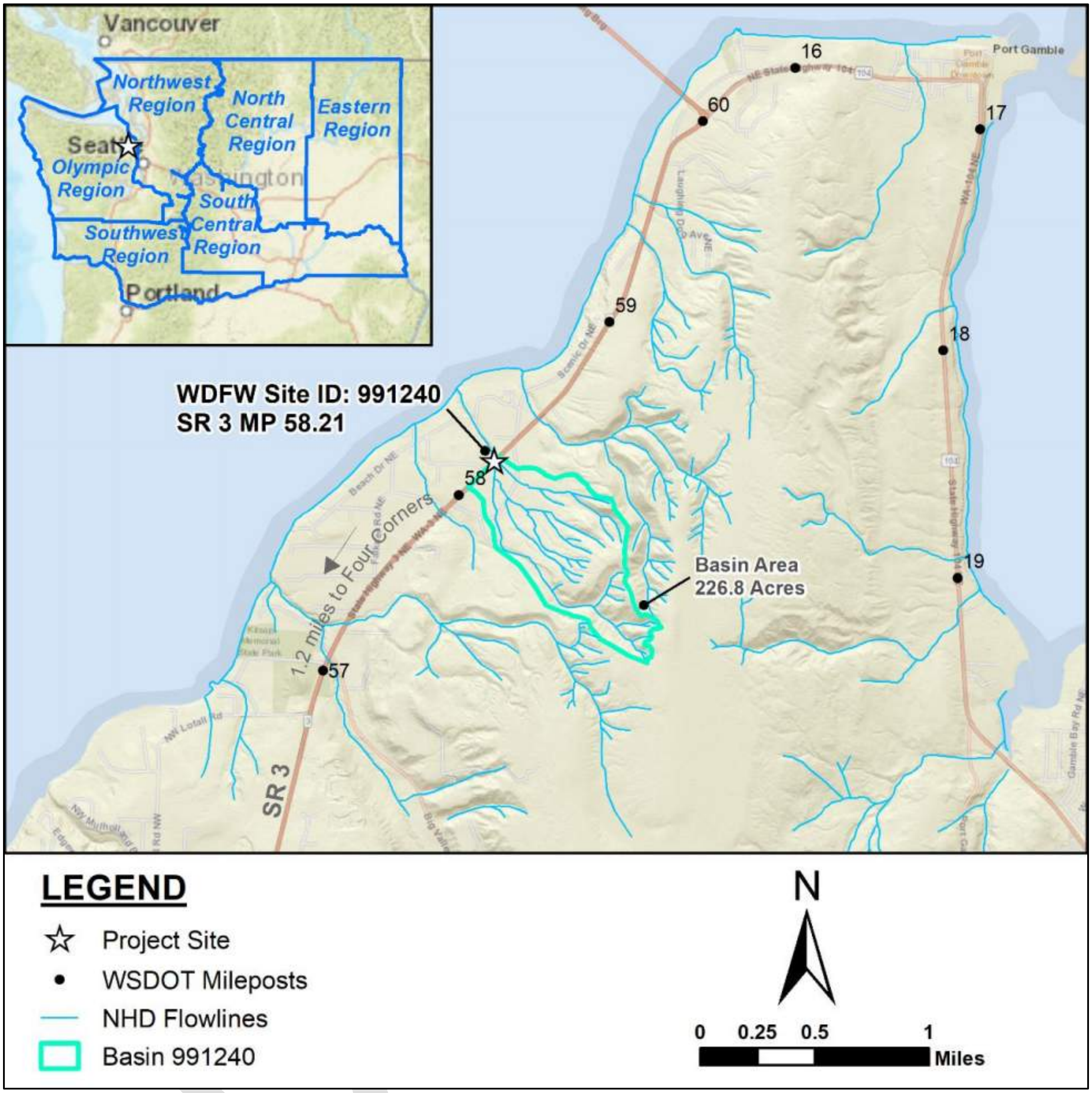

Figure 1. Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, geomorphology, regulatory floodplains, fish presence, wildlife crossing priority, and site observations. This was performed using site visit observations and desktop research with resources such as the United States Geological Survey (USGS), United States Department of Agriculture (USDA), Washington State Department of Natural Resources (DNR), Federal Emergency Management Agency (FEMA), and WDFW, along with past records such as observations, maintenance, and fish passage evaluation.

2.1 Site Description

The project culvert is a slope barrier with zero percent passibility. The project culvert is not listed as a Chronic Environmental Deficiency site. No emergency maintenance repair history was found for this site. During site visit 2, the landowner of the property downstream of the project crossing said that he had removed large woody material (LWM) from the creek to avoid flooding. No LWM was observed within approximately 250 feet of the outlet, indicating wood had been artificially removed from that region (Section 2.6.4). The exact nature of this maintenance is not known, but there was evidence of cut wood seen in the channel. There are no other records of flooding or maintenance at this site. There is potential habitat gain of approximately 6,014 LF.

2.2 Watershed and Land Cover

The drainage area contributing to Crossing 991240 along SR 3 is 226.8 acres and is located to the west of Port Gamble Forest Heritage Park on the Kitsap Peninsula. Two tributaries converge approximately 50 feet upstream from the project culvert inlet. The primary channel flows roughly southeast to northwest and under SR 3 at Crossing 991240. This channel will be referred to as the “main channel.” A tributary from the northeast confluences with the main channel just upstream of the crossing. This tributary will be referred to as the “east tributary” (Figure 2).

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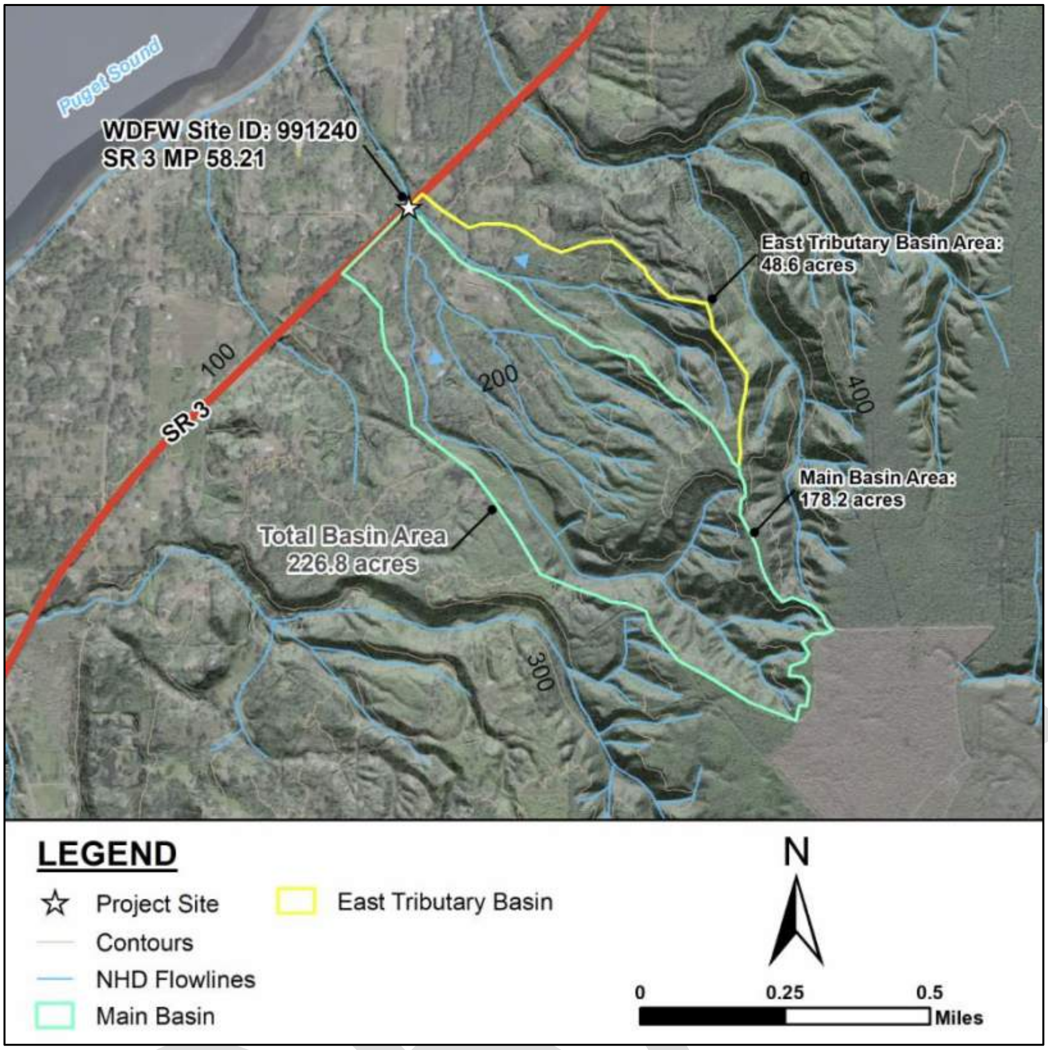

Figure 2. Watershed map

According to the National Land Cover Database (NLCD) the watershed consists of mostly forest with medium intensity developed land occupying 0.5 percent of the basin (NLCD, 2019) (see Table 1). The NLCD classifies Developed, Low Intensity as between 20 percent and 49 percent, so the average of 35 percent was used to determine the impervious area in that landcover classification. A similar procedure was done for Developed, Medium Intensity and Developed, Open Space. The resulting impervious area is 5.3 acres, which calculates out to 2.3 percent of the entire watershed (Table 1).

Watershed elevations range from 79 feet, North American Vertical Datum of 1988 (NAVD88), near SR 3 to 450 feet in the upper watershed (Figure 2). The prevailing land use within the watershed is young evergreen forest. No signs of logging were present within the reach observed during site visit 2. No logging is anticipated in the project vicinity any time soon. The terrain would make logging difficult within the watershed. This supplies woody debris and sediment to the stream.

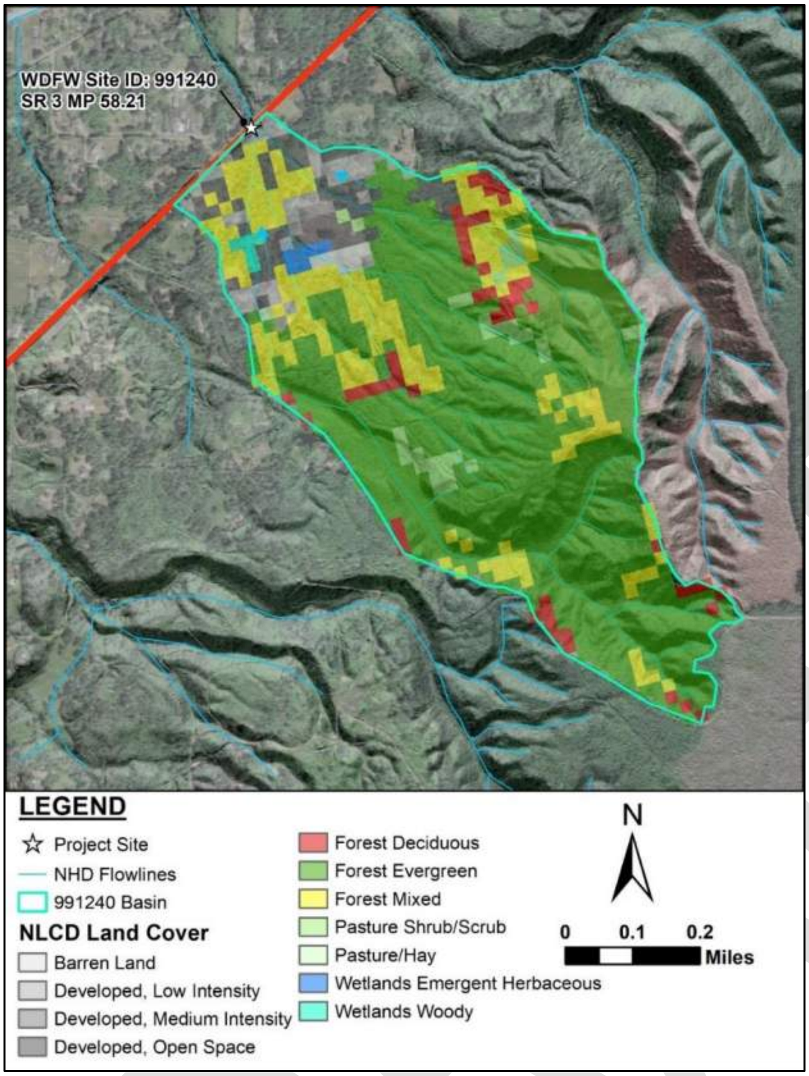

Figure 3. Land cover map (NLCD 2019)

Table 1. Landcover

Landcover class	Basin Coverage (acres)	Basin coverage (percentage)	Average percent impervious	Impervious area (acres)
Barren Land	1.6	0.7%	-	-
Developed, Low Intensity	9.1	4.0%	35	3.2
Developed, Medium Intensity	1.1	0.5%	65	0.7
Developed, Open Space	14.0	6.2%	10	1.4
Forest Deciduous	9.4	4.1%	-	-
Forest Evergreen	143.3	63.2%	-	-
Forest Mixed	38.4	16.9%	-	-
Pasture Shrub/Scrub	7.3	3.2%	-	-
Pasture/Hay	0.2	0.1%	-	-
Wetlands Emergent Herbaceous	1.3	0.6%	-	-
Wetlands Woody	1.1	0.5%	-	-
Total	**232.6**	100.0%		**5.3**

2.3 Geology and Soils

The project site is located within the Puget Lowland, a low-lying area between the Cascade Range to the east and the Olympic Mountains to the west. The geology of the Puget Lowland reflects multiple periods of glacial advance and recession occurring throughout the Pleistocene epoch. Geology within the project crossing vicinity was obtained from geologic mapping (Figure 4) (DNR, 2010). The 1:100,000 scale geologic mapping shows five geologic types adjacent to the crossing, all of which are from the Pliocene period: Qga (advanced continental glacial outwash), Qb (beach deposits), Qgd (continental glacial drift), Qgo (continental glacial outwash), Qgt (continental glacial till).

Qgt (continental glacial till) underlies the north side of the Kitsap Peninsula within the project vicinity (DNR, 2010). The till deposits are found on hills, ridges, slopes, and valley sides, either as the topmost unit or beneath younger outwash deposits. Till consists of a non-sorted mixture of mud, sand, pebbles, cobbles, and boulders. The till deposit is generally compact and often is referred to as hardpan, which has high resistance to surface erosion and landslide. The Port Gamble area consists of a till-underlain terrace with drift and outwash deposits mostly near the shoreline (Figure 4).

Qgo is continental glacier outwash. The outwash consists of mostly clean, gray, pebbly sand with increasing amounts of gravel near the ground surface. This was observed in the downstream reach of the project crossing (Figure 18). Glacial drift (Qga) is mapped in several of the drainage subbasins within the project watershed.

The geological information described above is similar to what was observed at the site (Section 2.1). As a result, the geology in the project vicinity has potential to adapt to changes caused by replacing the existing culvert which currently restricts substantial flow during extreme events. A geotechnical scoping memorandum was made available for this site on September 2, 2022. Under roadway fill, results show cohesionless, glacial deposits of very loose, silty sand from elevation 70 feet to 53 feet under SR 3. See sections 2.7.4 and 7.2 for discussion on long-term degradation potential (WSDOT Geotechnical Office, 2022).

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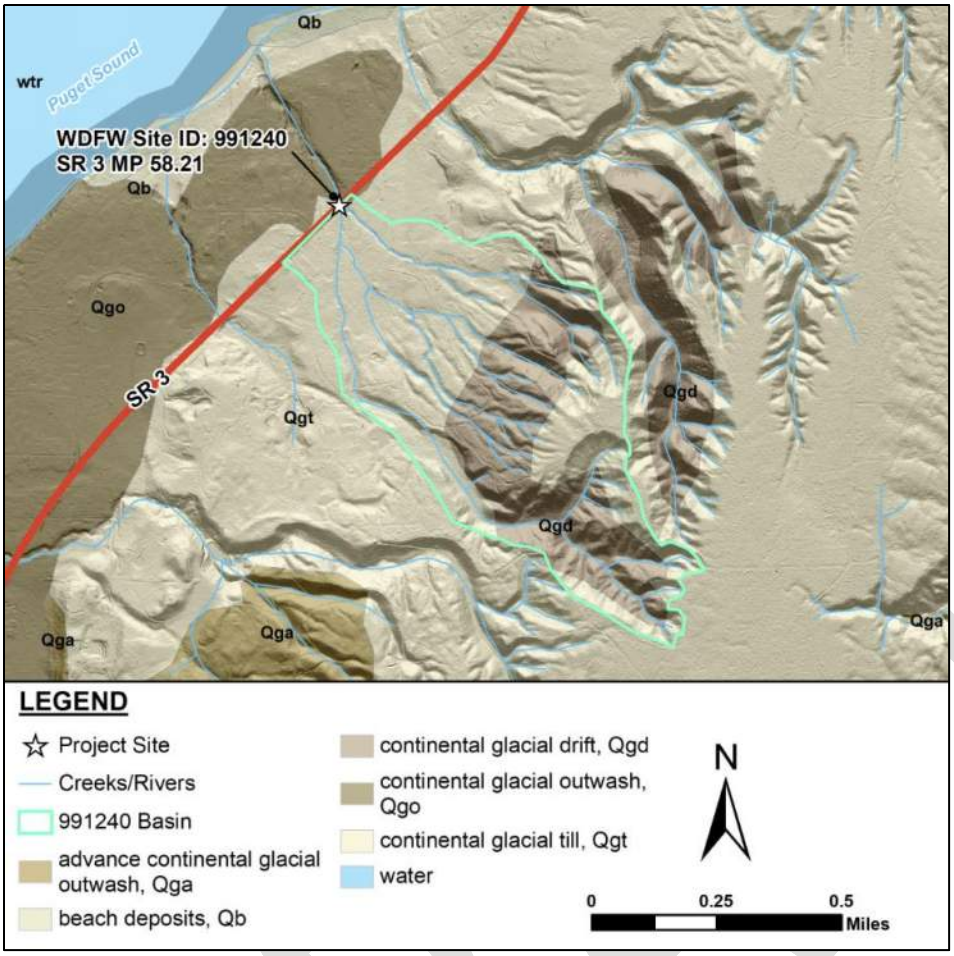

Figure 4. Geologic map

Soils in the basin were mapped using the USDA Natural Resource Conservation Service soils database (NRCS, n.d.). The largest soil unit in the watershed is Poulsbo-Ragnar complex (Figure 5). This unit is moderately-well drained and the predominant vegetation coverage is forest. Near the crossing the soils are Norma fine sandy loam, which is a deep and poorly drained soil. There is often a high water table associated with this soil class. A high water table and saturated soils were seen upstream of the crossing during the site visit on December 2, 2021.

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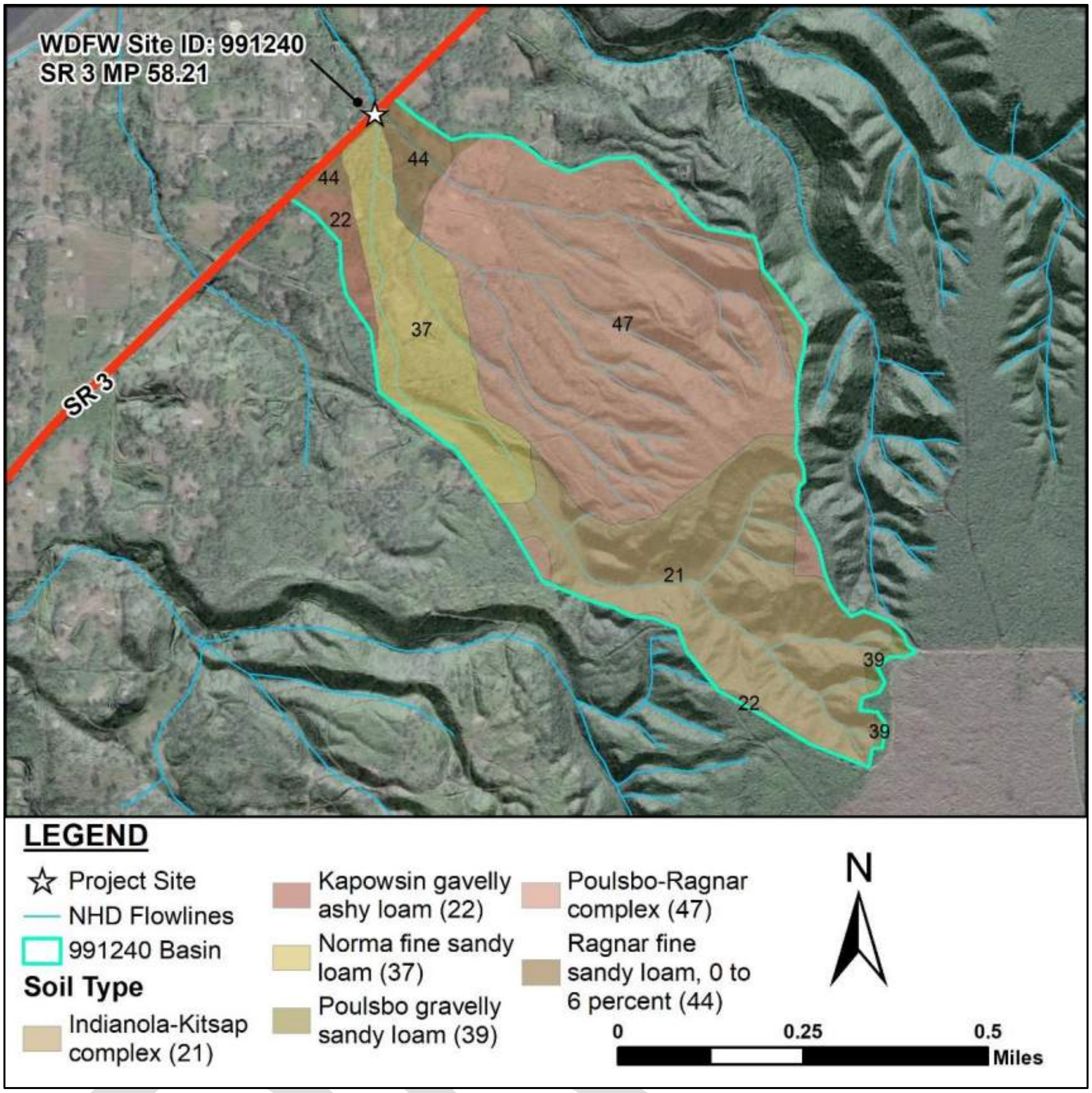

Figure 5. Soils map

2.4 Fish Presence in the Project Area

The Rapid Sample Full Survey (RSFS) and the WDFW barrier inventory report identified Coho salmon (*O. kisutch*), Steelhead (*O. mykiss*), Sea-run cutthroat (*O. clarki*), and resident trout as potentially benefiting from the project (WDFW 20119, unpublished data). However, the Statewide Integrated Fish Distribution (SWIFD) database does not show any documented presence of salmonid species at the project crossing (NWIFC and WDFW, 2022).

Puget Sound Coho are not listed under the ESA. Steelhead in the area are part of the Puget Sound Distinct Population Segment, which are labeled as threatened (Cram, et al., 2018). None of the resident or sea-run cutthroat trout Distinct Population Segments are listed under the Endangered Species Act (Coastal Cutthroat Trout Symposium, 2008).

Table 2. Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho	Presumed	WDFW fish passage database	Not listed
Steelhead	Presumed	WDFW fish passage database	Threatened
Sea-run Cutthroat	Presumed	WDFW fish passage database	Not listed
Resident Trout	Presumed	WDFW fish passage database	Not listed

2.5 Wildlife Connectivity

The one-mile-long segment of UNT to Hood Canal adjacent to the project crossing had no ranking for Ecological Stewardship and is a low priority for wildlife-related safety by WSDOT Headquarters (HQ) ESO. Adjacent segments to the north and south had no Ecological Stewardship rank, and either low or no wildlife-related safety rank. A wildlife connectivity memorandum will not be provided at this site and additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes.

2.6 Site Assessment

Three site visits were performed at the UNT to Hood Canal Crossing 991240 located along SR 3 MP 58.21 in Kitsap County, Washington. The first site visit (site visit 1) was conducted by WSDOT survey crews to gather data regarding the geometry of the existing channel and current infrastructure elevations and stationing. The second site visit (site visit 2) was done by PACE design staff on December 2, 2021, to determine the design reach, bankfull width (BFW), pebble count, etc. The third (concurrence) site visit (site visit 3) occurred on February 2, 2022, and included PACE, WSDOT, Suquamish Tribe, and Port Gamble S'Klallam Tribe representatives. The site assessment based on the data collected during site visit 2 was updated to reflect additional data, findings, and discussions that occurred during site visit 3. During site visit 3, the previous reference reach was divided into separate upstream and downstream design reaches. Also during site visit 3, three additional BFW measurements were taken which replaced previous BFW measurements from site visit 2 (Section 2.7.1 and Section 2.7.2). The field reports from site visit 2 and site visit 3 can be found in Appendix B.

The project crossing carries runoff from the Port Gamble Heritage Forest through the UNT to Hood Canal. The inlet opening is at the toe of about 10 feet of road fill with steep banks approximately 2:1 slope on two sides. At the time of site visit 2, the outlet emptied into an approximately 1-foot-deep and 15-foot-long plunge pool (Figure 14). The slope of the crossing was not verified at the time of the site visit 2; however, the culvert was measured to be 2 feet in diameter.

The upstream reach is contained in a shallow valley with stands of salmonberry surrounding the inlet and populating the floodplains. The east tributary joins the main channel 53 feet upstream of the inlet (EX STA 15+03). At the upstream end of the survey there is another crossing (Site ID 991906) through a private road that leads to one of the adjacent residences. The culvert is a 3.0-foot-diameter, 29.6-foot-long corrugated metal pipe. The channel near the upstream culvert displays characteristic effects of culvert crossings including a perched outlet and incision downstream along with minor aggregation at the inlet. This structure likely acts to somewhat limit bedload sediment supply to the project crossing (Section 4.2.3.2).

In the downstream reach the creek is heavily incised, with evidence of bank degradation. There is one residence next to the creek with the other side being used as an undeveloped storage lot. At EX STA 10+06, a partially buried log acts as a weir stretching across the stream. Just downstream of this structure, a property boundary fence crosses the stream. The fence is in poor condition and does not impede flow or restrict access to the stream (Figure 6).

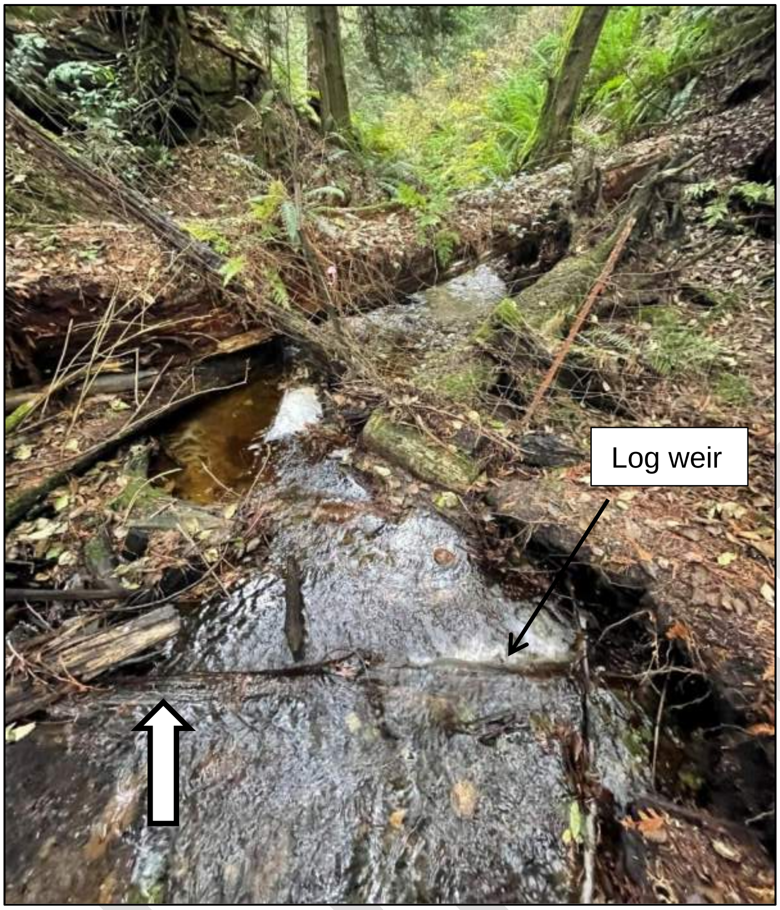

Figure 6. Property line fence and cut wood

2.6.1 Data Collection

During site visit 2 a project crossing design reach was identified 100 to 180 feet upstream (US) of the culvert inlet. It was decided by the design team that the reach is in a stable, natural condition and is less incised than the channel downstream of the crossing. As the upstream design reach is upstream of the confluence with the east tributary, a second design reach 250 feet downstream of the crossing was identified. See Section 2.7.1 and Section 3 for more discussion about how the two design reaches were used to inform the proposed channel. Three bankfull width (BFW) measurements were taken in the upstream design reach and are marked as US BFW #1-3 in Figure 7. Three additional BFW measurements were taken downstream (DS) of the crossing and are labeled as DS BFW #1-3. Three Wolman pebble counts were performed at the project site, two in the upstream reach and one in the downstream reach (Figure 7). One of these upstream pebble counts was later removed. The sediment in this stream is made up mostly of fine to small gravel and the occasional cobble and boulder. More discussion of the sediment is in Section 2.7.3.

The survey data for this site was initially delivered on January 10, 2022, by WSDOT survey. An inaccurate data point was found in the initial survey data which resulted in the second survey surface being delivered on January 25, 2022. The survey extends about 340 feet upstream and downstream of the culvert.

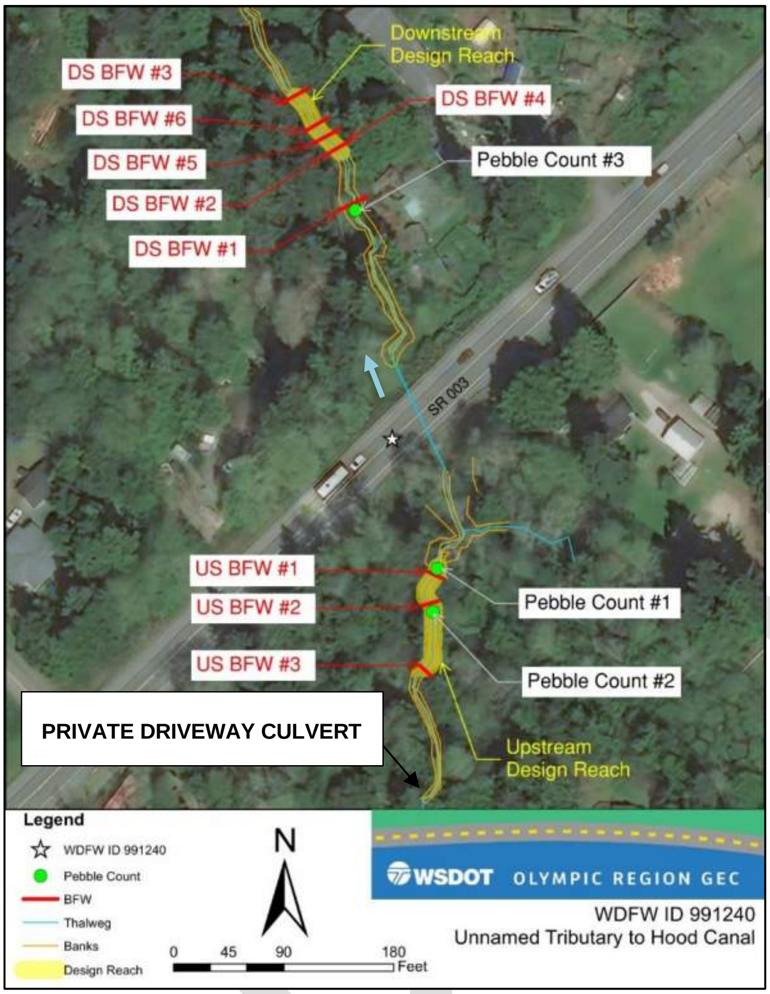

Figure 7. Design reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The existing project culvert is a 99.2-foot-long, 2-foot-diameter, round concrete culvert. The WDFW fish passage database shows that the crossing has a 4.0-percent slope and states that slope is the reason this structure is a barrier to fish (WDFW, 2019). However, WSDOT survey crews found the slope to be 5.1 percent (Figure 42). The project culvert alignment is approximately 20 degrees from perpendicular to SR 3. During site visit 2 the culvert outlet was overgrown with vegetation and there was a 1-foot-deep pool (Figure 14). At the time of site visit 3, the vegetation had been cleared away (Figure 15).

A driveway culvert is present approximately 355 feet upstream of the project crossing with the inlet at EX STA 17+85. The culvert was not listed in the WDFW fish passage database (WDFW, 2019). WSDOT survey found the 3-foot-diameter culvert to be 30.0 feet long and have a slope of 1.8 percent (Figure 13).

The crossing inlet is covered by dense brush and is partially filled with organic debris and sediment (Figure 8). Upstream of the crossing, the stream channel is approximately 5 to 10 feet wide and there is a floodplain bench approximately 1 to 2 feet above the stream channel for the majority of the surveyed reach. The floodplain is in a confined valley (Figure 10). See Section 6.1 for additional floodplain information. The wetted width on December 2 was approximately 5 feet, although it appeared recent higher flows had been much wider and spilled out onto the floodplain in areas. Surrounding the inlet and extending from the top of the roadway prism to approximately EX STA 15+00 is a dense thicket of vegetation that crowds around the channel (Figure 9). The east tributary joins the main channel in this thicket of vegetation and creates a mudflat. The main channel banks gently slope upward and transition into the surrounding floodplain.

For the next 80 feet upstream of the east tributary confluence (approximately EX STA 15+00 to EX STA 15+80), the slope steepens slightly and the stream is dominated by forced pool-riffle morphology. This section of stream is characterized by forced sinuosity as the stream flows around several rootwads and LWM. The banks in this region become steeper and more defined (Figure 10). At approximately EX STA 15+80 there is a floodplain that extends to the west approximately 20 feet from the channel (Figure 11). At higher flows it is likely that the stream is well-connected with this floodplain. Farther upstream the reach returns to riffle morphology, with established banks and benches on the sides (Figure 12).

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Figure 8. Culvert inlet

Figure 9. Thicket just upstream of culvert

Figure 10. Rootwads and US BFW #1

Figure 11. Floodplain and location of US BFW #2

Figure 12. US BFW #3

Figure 13. Outlet of driveway culvert

In the downstream reach the channel is confined in a ravine with steep slopes. At the bottom of the ravine there are small floodplain benches descending to steep, undercut, unstable banks along much of the channel. There is a narrow floodplain bench 2 to 3 feet above the channel along most of the reach. The channel is contained within a 10- to 30-foot valley bottom. Immediately downstream of the outlet there is a scour pool. The scour pool is approximately 3 feet long, 2 feet wide, and 1 foot deep (Figure 14). Beginning approximately 15 feet downstream of the outlet the banks become vertical with exposed roots showing and a sharp angle at the top-of-bank break in slope (Figure 16). The stream makes a couple of sharp bends in this reach. These types of bends are usually forced by LWM or boulders, but no obvious forcing features could be seen, possibly due to the landowner removing wood from the channel. It appeared that the channel had recently incised down and was actively widening and eroding the banks (Figure 18).

At approximately EX STA 12+40 the channel widens slightly and the vegetation on the bank transitions from blackberry to salmonberry and dogwood. The channel in this reach appears to have recently undergone 0.5 to 2 feet of incision. At approximately EX STA 10+90 the right bank of the channel is undercut (Figure 19). The rounded break in slope forming the top of bank indicates any incision here is older or slower than the incision upstream. There was also glacial till observed in this section of the downstream reach. Cut pieces of wood were observed in the channel, which confirms the property manager account of cutting wood in the channel. Approximately 350 feet downstream of the crossing (near the property boundary) a large downed tree was observed in the channel, with other small pieces of wood racking near the larger log (Figure 6).

Figure 14. Culvert outlet at site visit 2

Figure 15. Culvert outlet at site visit 3

Figure 16. Typical downstream banks with bench


Figure 17. DS BFW #3 looking downstream


Figure 18. Exposed banks indicate recent bank instability and incision at BFW #4

Figure 19. Steep undercut bank

As-builts have been obtained for the road, but no culvert as-builts have been obtained. The as-builts and the WSDOT maintenance records which have also been obtained show that there has not been any maintenance of the culvert by WSDOT. However, the property owners abutting the creek downstream of the crossing have been clearing the stream of downed wood. Habitat is negatively affected as fish have limited access to the upstream reach due to the undersized and steeply sloped concrete culvert. Removal of organic material from the stream limits the amount of habitat in the downstream reach.

2.6.3 Fish Habitat Character and Quality

In the WDFW Level I Barrier Assessment the potential species identified for this tributary are Coho, steelhead, sea-run cutthroat, and resident trout. While the creek is small, it does contain good rearing habitat and some potential for salmonid spawning.

The flow in the upstream reach was approximately 1 to 6 inches deep in most places, with the streambed consisting mainly of gravel to cobbles (Figure 22). It is possible there could be some successful spawning activity, especially for smaller resident trout. There were several wood-forced scour pools with vegetation overhanging that could serve as protection from predators (Figure 21). These pools would serve as juvenile rearing habitat, likely for both over-summer and overwinter rearing. During large flood events it is likely there is good connection between the channel and the floodplain, which would offer additional slow velocity refuge habitat. At the first BFW measurement and pebble count there were caddis fly larva present on a significant portion of the substrate above 1 inch in diameter.

Figure 20. Typical riffle above the upstream design reach

Figure 21. Typical habitat in the upstream design reach upstream of the project crossing

Downstream of the crossing the main channel has substrate similar to the upstream, with the streambed consisting mostly of gravel to cobbles, allowing for the possibility of spawning activity. Boulders were seen in the downstream reach and not in the upstream reach, and these boulders created small scour pools as water was forced around them (Figure 22). These small pools could be used for juveniles or residents for rearing habitat. The majority of the reach was a shallow riffle with little complexity, and there were few pools that offered velocity refuge. The banks were undercut and there was vegetation overhanging the channel and lining the banks which would provide protection from predation as well as the possibility for increased foraging of terrestrial invertebrates (Figure 22).

Figure 22. Channel approximately 100 feet downstream, looking upstream

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

The watershed of UNT to Hood Canal is lightly developed. The creek drains primarily maturing stands of evergreen forest in its upper reaches and passes through low density rural/residential areas downstream of the crossing to the mouth of the creek at Hood Canal. The riparian corridor of the creek is mostly forested and undeveloped. There was no noted beaver activity at the site during the site survey. Landowner wood removal likely limits beaver potential in the downstream reach, but it is possible beavers could find suitable habitat upstream of the crossing. The 3-foot-diameter driveway culvert upstream of the project site limits the potential for large debris transport. If the driveway culvert were removed, the stream would still lack sufficient power to transport large logs.

The vegetation of this reach is typical of the region with Western red cedar (Thuja plicata), Douglas fir (Pseudotsuga menziesii), large leaf maple (Acer macrophyllum), and red alder

(Alnus Rubra) making up the majority of the trees, and sword fern (Polystichum munitum), spreading wood fern (Dryopteris expansa), and salmonberry (Rubus spectabilis) being the predominant groundcover lining the channel (Figure 23).

Figure 23. Western Red Cedar and Alder trees upstream

Trees appear to be generally healthy. Based on observed trees that have fallen close to the bank in the upstream reach, trees growing along the bank could eventually destabilize due to stream evolution processes. Trees are fairly spread out which results in a moderately-dense canopy cover.

Upstream of the crossing the channel contains a good deal of organic material. Up to approximately 50 feet upstream the channel is lined by a dense thicket, largely composed of salmonberry (Figure 24). Approximately 40 feet upstream of the crossing inlet the east tributary joins the UNT to Hood Canal. Above the thicket, the channel is a bit steeper with more defined banks and riffles. Upstream of this, two large trees which must have been growing close to the stream had fallen away from it (Figure 20 and Figure 21). Several mature Alder trees were also observed growing along the bank close to the location of the fallen trees. The remainder of the upstream reach contained significant LWM engagement with even low flow (Figure 25).

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Figure 24. Dense salmonberry upstream of the project crossing.

Figure 25. LWM engagement upstream of the project crossing.

Vegetation in the downstream reach is virtually identical to that in the upstream reach. During site visit 2 it was discovered that the landowner of the downstream reach had removed LWM on several occasions to avoid potential flooding. As a result, no large logs were observed within 250 feet of the culvert outlet. Farther downstream (EX STA 10+00) LWM was observed adjacent to the stream (Figure 26). Channel banks are either nearly vertical or undercut throughout the vast majority of the downstream reach (Figure 27).

Figure 26. LWM creating habitat complexity approximately 350 feet downstream of the project crossing

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Figure 27. Vertical banks with no established vegetation indicating active incision in the downstream reach, looking downstream

2.7 Geomorphology

Geomorphic information provided for this site includes selection of design reaches, the geometry and cross-sections of the channel, and both vertical and lateral stability of the channel of the UNT to Hood Canal.

2.7.1 Reference Reach Selection

As the crossing is at a geographical transition in the terrain and immediately downstream of a tributary junction, the stream has distinct characteristics upstream and downstream of the project crossing. To construct the most sustainable crossing possible, two design reaches were used to inform the proposed crossing design. The upstream design reach (approximately EX STA 15+50 to 16+45) informed the proposed channel shape. The downstream design reach (approximately EX STA 10+30 to 11+00) informed the design channel slope and MHO. Pebble count data from both design reaches were used to size the streambed boulders.

The upstream reach is in a less confined and still coalescing watershed, and the downstream reach lies in a more confined, well-defined ravine with steep slopes and limited floodplains. This transition can be seen in the Figure 2 watershed map where upstream of SR 3 there are several branches of the stream coming together within the gently sloping terrain, and on the downstream side there are no tributaries to the ravine as the creek steepens as it cuts through the uplifted bluff and makes its way to sea level. This transition in the terrain and channel is natural and can be seen in other nearby watersheds draining west to Hood Canal. However, the undersized culvert has likely contributed to the observed upstream and downstream differences by acting as a hard grade control and limiting the most recent channel evolution from naturally migrating from the downstream to the upstream channel reaches. The culvert may also be limiting sediment transportation from upstream to downstream reaches. Combined with the potential removal of wood by landowners, these factors may all be contributing to the observed incision and widening in the downstream reaches.

To construct the most sustainable crossing possible, two design reaches were used to inform the proposed crossing design. The upstream design reach (approximately EX STA 15+50 to 16+45) informed the proposed channel shape. The downstream design reach (approximately EX STA 10+30 to 11+00) informed the design channel slope and MHO width. Pebble count #1 and pebble count #3 were used to design the streambed. At site visit 3, it was decided to use channel geometry from the upstream design reach (excluding the less-defined channel at BFW #2) to inform the proposed channel shape as this reach appears to have less anthropomorphic impacts and represents better fish habitat (Figure 7 and Figure 38). The channel here has defined banks and small overbank areas with good connectivity. The habitat features created by abundant woody debris and vegetation cover make this upstream reach an appropriate location for crossing design reference. The upstream reach has consistent slope and sediment size and does not show the signs of the recent incision seen downstream (Figure 28). However, this portion of the channel does not include flow from the east tributary channel, so upstream BFW measurements were not included in the average design BFW for determining the future crossings MHO (Section 2.6.1).

The crossing lies at a transition in slope with the downstream design reach slope of 4.6 percent, and the upstream design reach slope of 3.4 percent (see Section 2.7.4). To provide a smoother and more natural tie-in, the slope from the downstream design reach was used to inform the design slope. BFW measurements were taken from the downstream design reach after the east tributary combined with the main channel (Figure 29).

Figure 28. Upstream design reach at BFW 3, looking upstream

Figure 29. Downstream design reach looking upstream

2.7.2 Channel Geometry

The upstream design reach was used to inform the proposed channel shape (Section 2.7.1). This strategy was decided with comanagers during site visit 3 as the upstream reach appears less incised. The area chosen to reference channel geometry is upstream of the east tributary confluence and therefore, has a reduced amount of flow. Accordingly, the downstream design reach was chosen to inform the design channel slope and MHO. In both the upstream and downstream design reaches the channel is relatively straight, with more localized forcing features such as large wood in the upstream reach. The average design BFW was used to size the MHO and the average upstream BFW was used to size the proposed channel geometry.

In the upstream design reach banks are composed of loose soil covered with leaflitter. Some willow stands have grown close to the edge of the banks. Several logs lay along the banks (Figure 28). The bankfull channel is approximately 1 foot deep with 3- to 7-foot-wide floodplains. The banks of the bankfull channel are approximately 1 foot high with slopes less than 1H:1V (Figure 31). The stream within the upstream design reach has a moderate channel gradient of approximately 3.4 percent (Figure 30), similar to the upstream channel slope. It has a single-thread low-flow main channel. The upstream channel bankfull width ranged from 5.0 to 9.0 feet (Table 3). See BFW locations in Figure 7. The wetted area widens out substantially at approximately EX STA 15+80 to approximately 17.0 feet (BFW #2) due to significant groundwater interaction creating a saturated, muddy bench. The comanagers concurred that this location did not warrant replication in the crossing. Instead it was decided to focus on the channel shape just downstream at approximately EX STA 15+50 (Figure 31) with the understanding that upstream BFW measurements would not be used to size the MHO.

Table 3. Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured	Notes
US #3	9.0	No	**US #3 EX STA 16+30***	Stakeholder removed on 02/02/2022
US #2	17.2	No	**US #2 EX STA 15+80***	Stakeholder removed on 02/02/2022
US #1	5.0	No	**US #1 EX STA 15+48***	Stakeholder removed on 02/02/2022
DS #1	8.3	Yes	**DS #1 EX STA 12+02***	Stakeholder concurred on 02/02/2022
DS #2	7.3	Yes	**DS #2 EX STA 11+54***	Stakeholder concurred on 02/02/2022
DS #4	9.0	Yes	**DS #4 EX STA 11+54***	Stakeholder added on 02/02/2022
DS #5	6.0	Yes	**DS #5 EX STA 11+41***	Stakeholder added on 02/02/2022
DS #6	7.0	Yes	**DS #6 EX STA 11+24***	Stakeholder added on 02/02/2022
DS #3	6.7	Yes	**DS #3 EX STA 10+90***	Stakeholder concurred on 02/02/2022
Design Average BFW	**7.4**	-	-	Used to determine MHO
Average Upstream BFW	**5.8**	-	-	Used to determine channel geometry

*BFW Locations are approximate

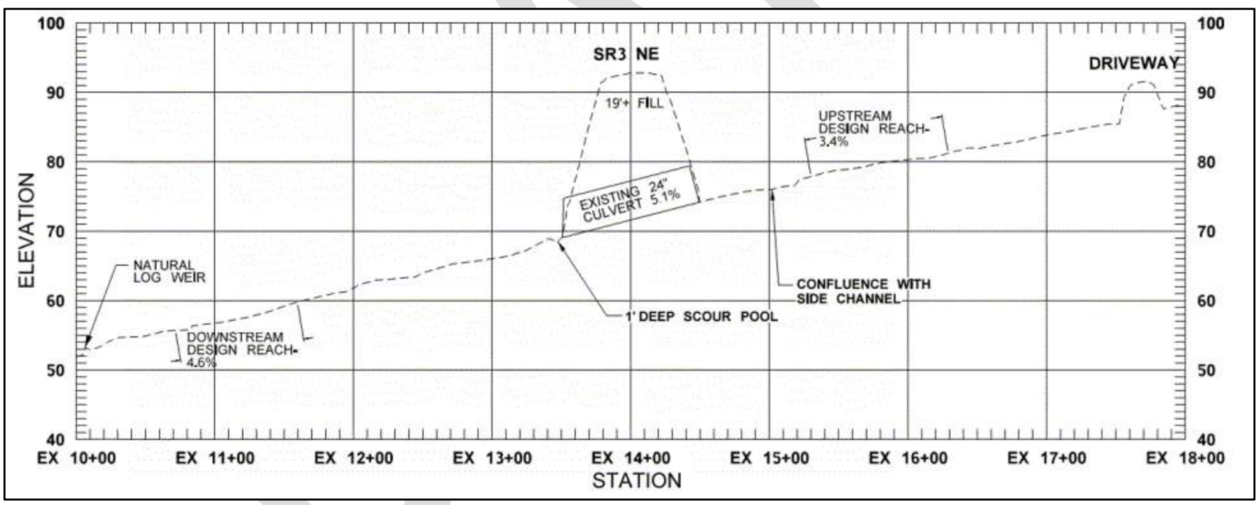

Figure 30. Longitudinal profile from ground survey

In the downstream design reach, banks are more incised, with what appeared to be a recently disconnected overbank bench on the right bank looking downstream ranging from 1 to 2 feet high with near vertical bank slopes (Figure 38). It was hypothesized that this recent incision has occurred as a consequence of wood removal and the culvert impacting channel evolution and sediment transport (Section 2.7.1). The slope of the downstream design reach is 4.6 percent. The proposed crossing will be designed based on this slope. This ensures bankfull widths used to size the MHO are representative of a reach with a similar slope and flow to the proposed channel. The site visit 3 concurred BFW measurements used for the average design BFW ranged from 6.0 to 9.0 feet with the average of 7.4 feet used to size the MHO of the proposed crossing.

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The width to depth ratio, defined as the BFW divided by bankfull depth, is 6.8 at US BFW #1. The bankfull width was 6.1 feet and the bankfull depth was 0.9 feet. This location was used to inform the design channel shape which has a width-to-depth ratio of 6.4. Existing channel dimensions were based on site observations and measurements. The recent incision seen downstream is evidence the stream is in Stage III of the channel evolution model (Simon & Rinaldi, 2006).

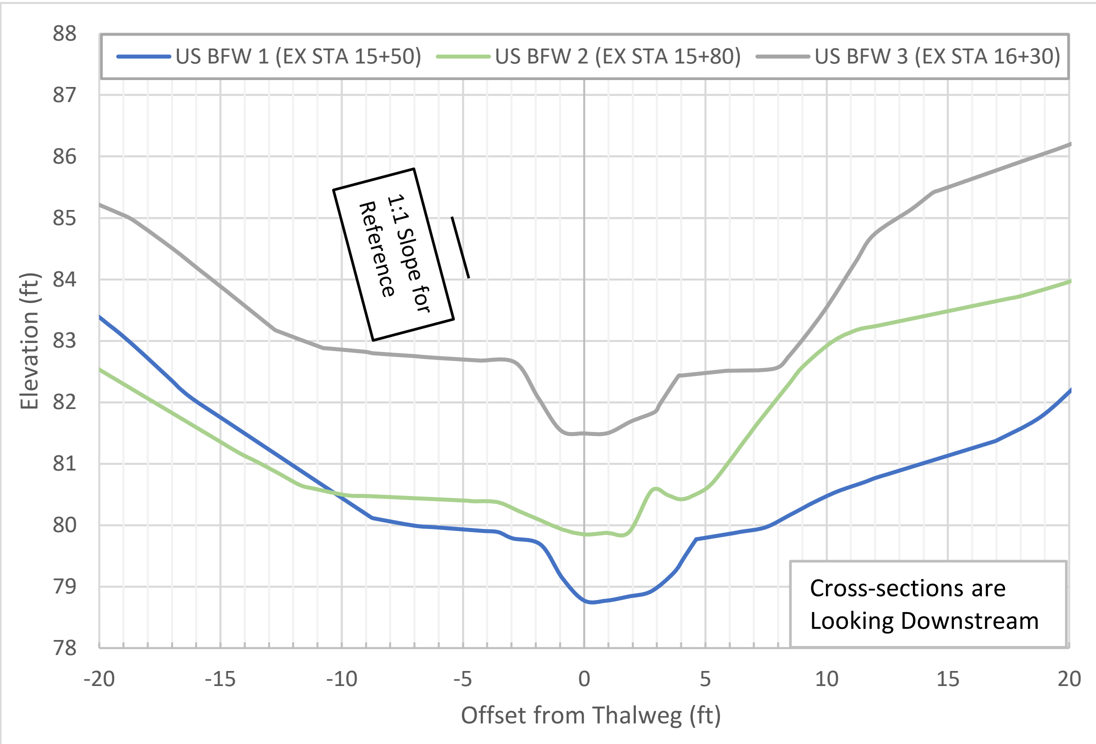

Figure 31. Existing cross-section examples

2.7.2.1 Floodplain Utilization Ratio

The WCDG (Barnard, et al., 2013) present the Floodplain Utilization Ratio (FUR) as a method to determine whether a channel is confined or unconfined. The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. The simulated 100-year flow width was used as FPW for this project. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel (Barnard, et al., 2013).

The culvert crossing at UNT to Hood Canal at SR 3 is severely undersized. Recent flow marks high on the floodplain were observed at site visit 2. In order to accurately determine the classification of the stream, an existing condition simulation was run with a 12-foot-wide culvert. This eliminates backwatering that occurs at high flow events that would otherwise provide misleading results regarding the confined or unconfined nature of the stream.

The FUR was calculated for the UNT to Hood Canal using 100-year flood widths in the upstream, downstream, and design reach channels (Section 2.7.1). The FUR was calculated as the simulated 100-year flood width divided by the design bankfull width of 7.4 feet; the results of the FUR calculations are shown in Table 4. The stream is notably more confined in the downstream reach (average FUR 1.4) than it is upstream of the crossing (average FUR 2.3). The FUR calculation corroborates the site visit 2 observations of the stream channel transitioning to a more confined setting below the crossing. All the calculated FURs in the surveyed domain are less than 3.0, indicating the channel is confined.

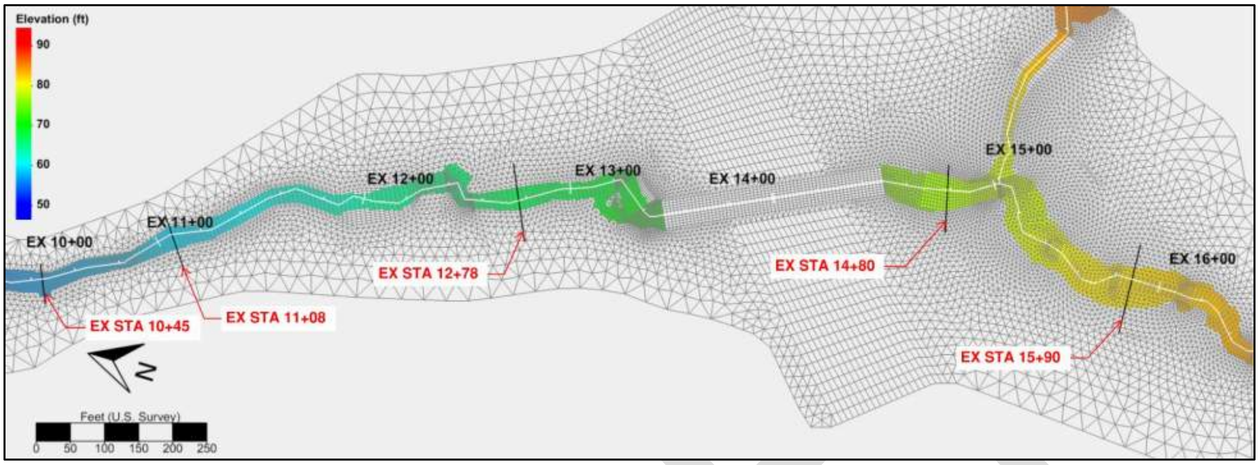

Figure 32. FUR locations

Table 4. FUR determination

Station	100-year FPW (ft)	2-year FPW (ft)	FUR	Confined/ unconfined	Included in average FUR determination
DS 10+45 (A)	10.7	7.6	1.4	Confined	Yes
DS 11+08 (B) (within DS design reach)	10.6	7.1	1.5	Confined	Yes
DS 12+78 (C)	10.1	7.1	1.4	Confined	Yes
US 14+80 (E)	15.4	9.2	1.7	Confined	Yes
US 15+90 (F) (within US design reach)	18.5	7.8	2.3	Confined	Yes
Average DS	**10.5**		**1.4**	Confined	-
Average US	**17.0**		**2.0**	Confined	-
Overall Average	**13.1**		**1.7**	Confined	-

2.7.3 Sediment

Three pebble counts were taken at the project site, but one was later excluded. Upstream pebble count #1 was taken at US BFW #1 (EX STA 15+50) (Figure 34 and Figure 35). Upstream pebble count #2 was taken at US BFW #2 (EX STA 15+80). This location was later discarded because it was taken at a muddy bench with groundwater inputs that was not considered representative of the entire stream reach. Downstream pebble count #3 was taken at DS BFW #1 (EX STA 12+02). Results of all pebble counts are shown in Table 5 and Figure 33.

Table 5. **Pebble Count Results**

Particle size	Pebble Count #1 US diameter (in)	Pebble Count #2 US diameter (in)	Pebble Count #3 DS diameter (in)	Average diameter for design (in)
Included in average?	Yes	No	Yes	-
D_{16}	0.4	0.05	0.2	0.2
D_{50}	1.1	0.7	0.8	0.9
D_{84}	1.9	2.4	1.7	2.0
D_{95}	2.6	4.4	4.5	3.8
D_{100}	3.0	5.0	12.0	12.0

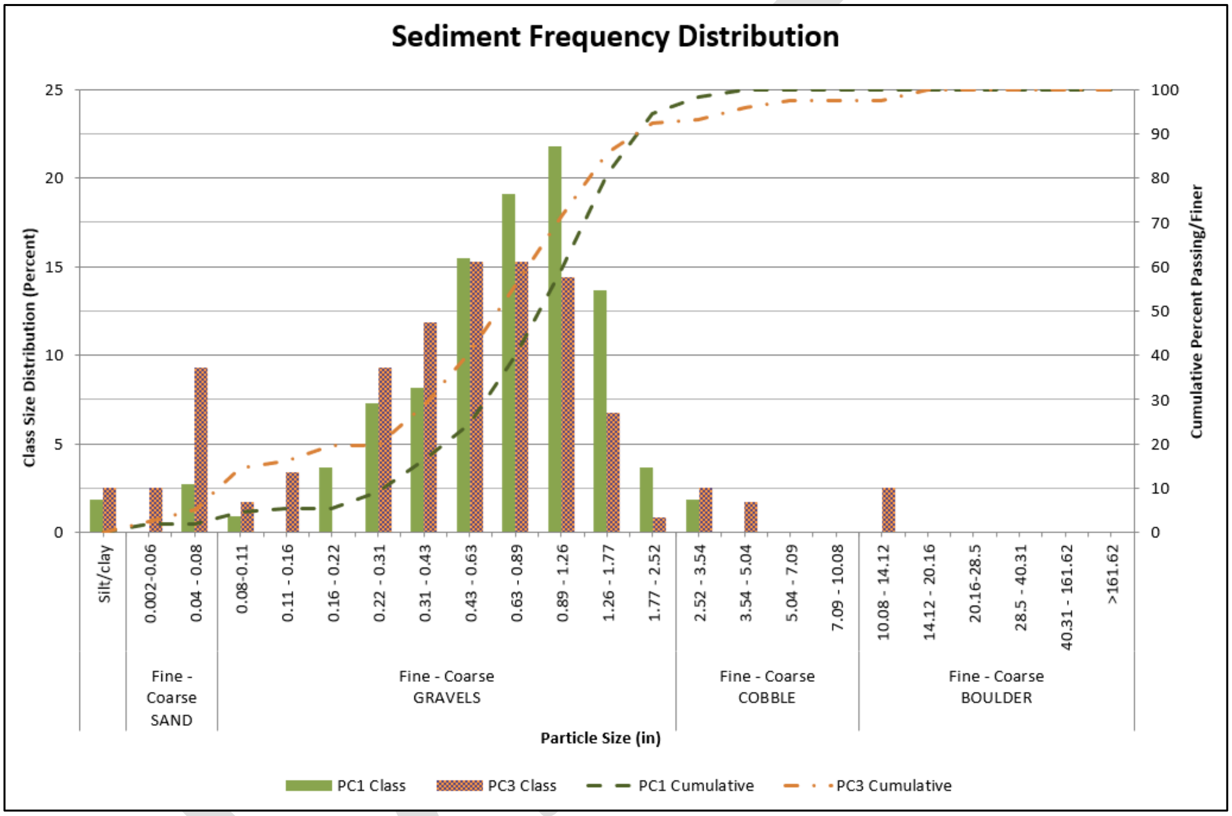

Figure 33. Sediment size distribution

In the upstream design reach, there were less visible large boulders observed than in the downstream design reach. This is likely due to the lower gradient of the upstream design reach, as well as the fact the existing culvert is acting as a grade control and the recent incision observed downstream did not propagate upstream. The incision may have exposed more of the boulders on the downstream side and the boulders in the upstream channel are still buried. Although there were some signs armoring in short rapid channel sections, the channel in general did not appear armored.

Figure 34. Pebble count #1 location

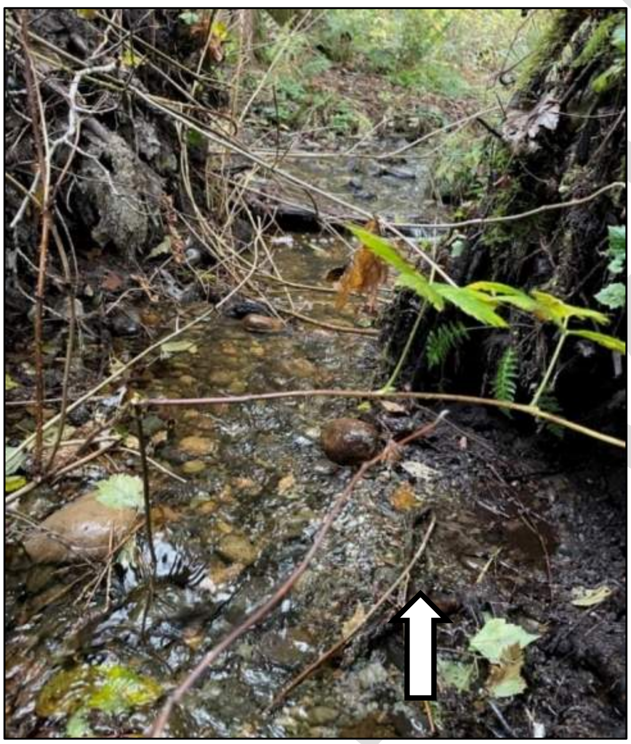

Figure 35. Closeup of sediment near pebble count #1

Pebble count #2 was taken at the same location as US BFW #2 at EX STA 15+80 (Figure 36, Figure 37) At this location, the right bank was formed by a log parallel to the flow and the left bank was not clearly defined, with groundwater seepage creating a wide muddy bench. At site visit 3, it was decided by comanagers that US BFW #2 should not be included in the average BFW calculation because that area had an unusually wide and saturated groundwater intrusion area; therefore, it was also deemed not suitable to include in the average pebble count data because sediment from this region is not representative of the stream’s natural state.

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Figure 36. Close up of sediment at upstream pebble count #2

Figure 37. Log forming right bank at US BFW #2 and pebble count #2

There were several large, stable boulders observed in the downstream design reach ranging from about 12 inches in diameter (Figure 39) to a single large lag deposit boulder over 2.5 feet in diameter (Figure 40) forcing a significant meander in the stream. Pebble count #3 was taken at DS BFW #1 at EX STA 12+02. The stream consisted of a riffle at this location with steep banks on both sides. The majority of sediment sampled at this location was coarse gravel with fines appearing with greater frequency as the count approached the banks (Figure 38). However, there was also a significant amount of both fines (mainly sands), along with scattered cobbles and boulders.

Figure 38. Close up of the sediment at pebble count #3

In the upstream design reach large wood and rootwads provided most of the channel-forcing features, although above the design reach large cobbles were observed close to the private driveway culvert at approximately EX STA 17+50 (Figure 13).

Figure 39. Smaller boulder around DS BFW #4b

Figure 40. Large boulder protruding from the bank about 200 feet downstream of the culvert

2.7.4 *Vertical Channel Stability*

The SR 3 crossing structure is located at a slope transition visibly evident in the LiDAR watershed profile in Figure 41. The long-term average upstream slope is approximately 3.5 percent and has a slightly convex profile shape, likely linked to the glacial till underlying the upper watershed. The downstream reach slope is approximately 4.5 to 5.0 percent, and transitions to a flatter slope before entering Hood Canal. The crossing is located at a change in grade, as well as a change in underlying geology (Section 2.3). As this slope transition creates a concave up-curve in the channel profile, channel aggradation is not considered likely. Approximately 1,000 feet downstream of the crossing the LiDAR indicates there is a short reach with a 13.7-percent slope. This point was not seen during any of the site visits. The cause and long-term stability of this point are unknown.

The downstream reach has evidence of bank undercutting and bank washouts (approximately 1.5 feet at EX STA 12+02), while the upstream reach has a shallower slope with significantly shorter banks (approximately 0.8 feet at EX STA 15+48). The banks in the upstream reach do not show the same signs of active erosion as the banks in the downstream reach. Discussion with the landowner of the property surrounding the downstream reach revealed the observed bank incision was a fairly recent event occurring rapidly a couple years prior during an especially wet spring. The landowner also indicated wood had been removed from the channel. It is possible the signs of instability in the downstream reach are to some degree related to this maintenance.

The ground survey confirms the LiDAR slopes and maps the slope upstream of the crossing as 3.4 percent and downstream is 4.6 percent (Figure 42). The ground survey shows a gradual steepening across the project site and does not pick up any significant knickpoints or other breaks in the longitudinal slope. A knickpoint is present at approximately STA 60+00. It was not determined whether this is a potential sediment source. The distance from the project crossing make the knickpoint unlikely to affect the proposed structure during its lifespan. The median sediment size was approximately the same between the upstream and downstream reaches, although cobbles and boulders were more common in the downstream reach. The larger boulders observed are likely glacial deposits that are being uncovered and were not transported by the stream. Sediment supply to the crossing is low as a result of the upstream driveway culvert. Therefore, the crossing currently has a low risk of aggregation.

The existing culvert is likely acting as a hydraulic grade control, preventing the observed downstream incision from migrating upstream. When the undersized culvert is removed, some of the incision observed downstream could migrate through the crossing to the upstream reach. An equilibrium slope indicates over the long term an additional two to four feet of scour is possible (see Section 7). Geotechnical boring data indicate that an erosion-resistant till layer is present at approximately elevation 52 feet under SR 3 (WSDOT Geotechnical Office, 2022). The long-term degradation depth is not expected to reach that elevation.

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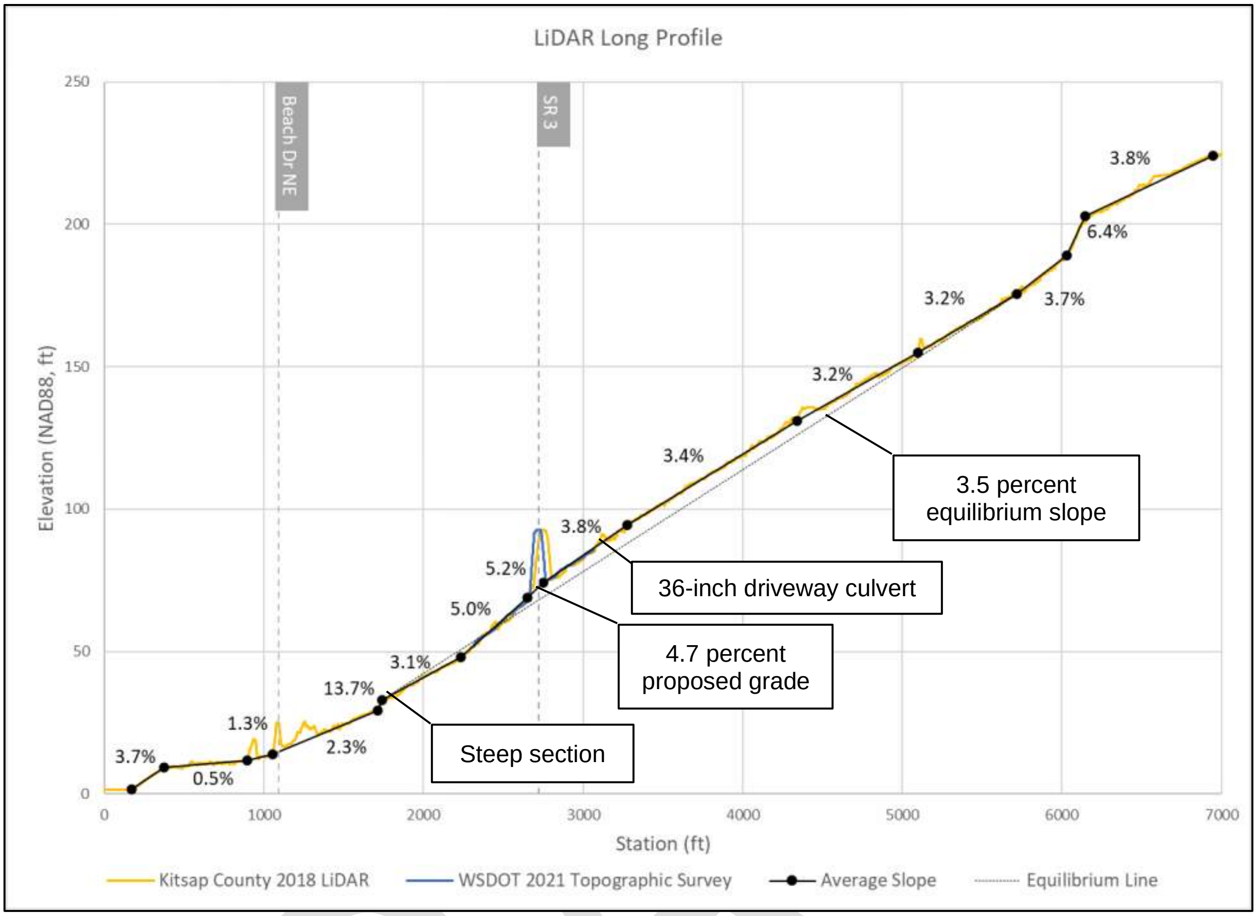

Figure 41. Watershed-scale longitudinal profile

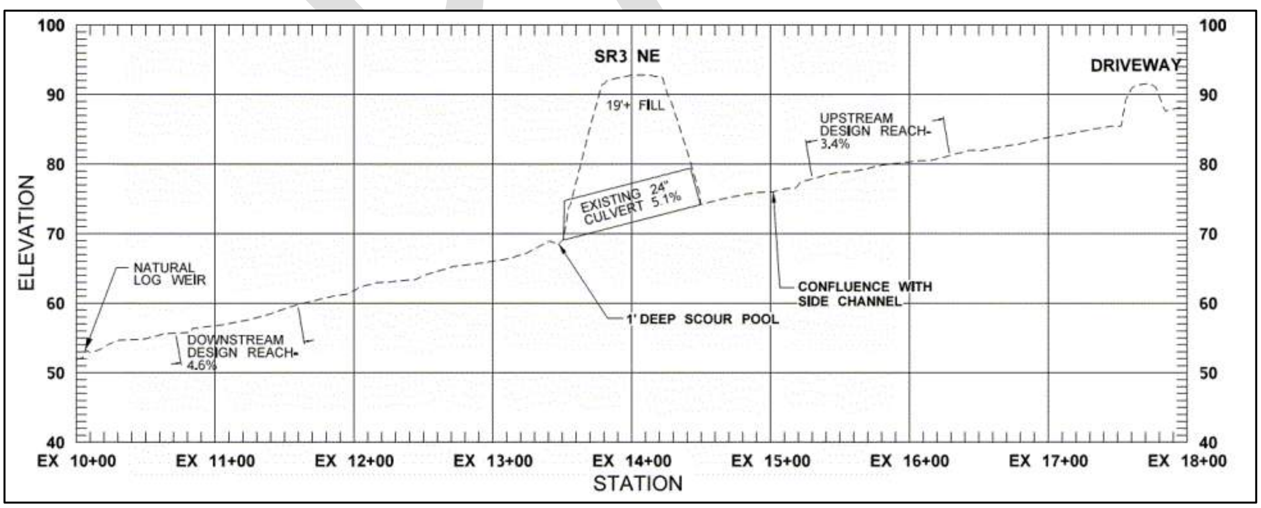

Figure 42. Longitudinal profile from ground survey

2.7.5 Channel Migration

Downstream of the project crossing the stream flows at the bottom of a 10- to 20-foot-deep ravine. The ravine is 60 feet wide at the top, and 15 to 20 feet wide at the bottom. There are small inset floodplain benches at the bottom of the ravine, but the channel is completely contained within the ravine bottom so large channel migration is unlikely. However, some erosion has occurred at the culvert outlet. Some sharp channel bends also existing directly downstream of the project crossing. The channel is quite sinuous. The soft banks show signs of recent erosion. Therefore, there is risk of some lateral migration within the larger valley walls in the downstream reach. The sinuosity ratio of the upstream design reach is 1.1.

Upstream of the crossing, the ravine transitions to a less-defined valley and the channel slope decreases. The east tributary joins the main channel just upstream of the crossing at EX STA 15+00. The banks are low in this location and exhibit mudflat characteristics. Here, the valley walls slope gently downward to the channel (Figure 8). Within this reach mild, natural migration of the channel within the shallow ravine bottom would be expected to occur over time. Large wood and rootwads next to the stream may have influenced the current channel alignment. Farther upstream, the channel develops a low floodplain and the ravine is only 6 to 10 feet deep (Figure 11). In this area, there is risk of channel migration across this floodplain, but the maximum horizontal distance of migration is likely limited to less than 10 feet by the ravine walls. This possible migration would be expected in a channel of this size, slope, and bank composition. However, while the channel has significant sinuosity and relatively soft and erodible banks, it shows little sign of recent erosion.

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3 Hydrology and Peak Flow Estimates

Chapter 2 of the WSDOT Hydraulics Manual provides guidance for the selection of the most appropriate method of hydrologic analysis (WSDOT, 2022a). Methodologies recommended in order of preference for ungauged basins are USGS Regional Regression Equations, Gauge Basin Transfer with Regional USGS equations, and Continuous Simulation Hydrologic Model approach.

The USGS Regional Regression Equations were used because no appropriate stream gauge data was available. These equations are intended for rural and predominately undeveloped basins areas. The project watershed is mostly undeveloped with 2.3 percent of the area being impervious (Table 1 and Figure 3). This is less than the 5 percent maximum allowed to use the Regional Regression Equation (WSDOT, 2022a). The mean annual precipitation of 36.6 inches is within the range of 33.3 to 168 inches which meets the requirement for Region 3 in Washington (Mastin, Konrad, Veilleux, & Tecca, 2017).

The Regional Regression Equations have a basin size requirement between 0.08 and 2,605 square miles. The watershed contributing to the main channel is 0.4 square miles, and the watershed contributing to the east tributary is 0.08 square miles. The east tributary is included as a separate flow input into the SRH-2D model because its confluence with the main channel is within the survey extent. Regional Regression Equations were run for each watershed independently.

The main channel basin lies to the southwest and the east tributary basin lies to the northeast. The standard regression equation flow rates modeled in SRH-2D at the 2-year (5.1 and 1.7 cfs respectively) resulted in water surface elevations (WSE) significantly below the top of bank in the upstream design reach. This was not consistent with what was observed at the site, and it was determined that the regression estimated flows were likely lower than true flows. The regression method recognizes uncertainty due to factors that are unable to be accounted for. To match observations in the field, the hydrology was increased halfway between the regression result and the upper 90 percent confidence interval. Model results using these adjusted flows better matched measured BFWs and provided a better representation of recent upstream floodplain inundation observed during site visits 2 and 3 as described below.

This methodology resulted in an estimated 2-year flow in the main channel of 7.7 cfs and in the east tributary of 2.6 cfs. At the 500-year and 2080 100-year flows, the model shows significant backwatering in the main channel upstream of the existing culvert. Backwater is a result of flow being restricted by a hydraulic control which causes an increase in WSE upstream. In this case, the project culvert is the hydraulic control causing the backwater condition. This hydraulic condition is consistent with what was observed in the upstream reach during site visits 2 and 3. This also agrees with field observations of floodplain sedimentation above the small-sized culvert (Figure 8 and Figure 9). Estimated adjusted regression flows are shown in Table 6.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passibility for all expected life stages and species in a system. The summer low-flow conditions are unknown.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 38.6 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 44.1 percent, yielding a projected 2080 100-year flow of 55.6 cfs.

Table 6. Peak flows for UNT to Hood Canal at SR 3

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 3) (cfs)		
	Main Channel	East Tributary	Combined
2	7.7	2.6	10.3
5	12.6	4.2	16.8
10	16.1	5.3	21.4
25	21.1	6.9	28.0
50	24.9	8.2	33.2
100	29.1	9.5	38.6
200	33.7	11.0	44.6
500	40.4	13.3	53.7
Projected 2080 100	42.0	13.7	55.6

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4 Water Crossing Design

This section describes the water crossing design developed for SR 3 MP 58.21 UNT to Hood Canal, including channel design, MHO, and streambed design.

4.1 Channel Design

The design proposes a two-stage channel consisting of a primary bankfull channel with overbank floodplain benches on each side. Both planform and cross-sectional variability will be created with channel complexity features described in Section 4.3.2. The proposed design consists of a constant channel gradient within the restored channel area, with an assumption that localized vertical variability will naturally develop around the forcing features over time.

4.1.1 Channel Planform and Shape

As described in sections 2.7.1 and 2.7.2, the upstream design reach was used exclusively to inform the proposed planform and cross-section shape while the downstream design reach informed the design channel slope and MHO. During site visit 3, it was suggested that the proposed channel geometry should attempt to reflect the less incised upstream design reach. Accordingly, the design channel dimensions were created based on surveyed existing channel geometry at EX STA 15+50 within the upstream design reach (Figure 43). During site visit 3, it was also decided to scale the upstream design channel BFW proportional to the additional flow contributed by the east tributary downstream. However, upon running initial model flows based on unscaled upstream channel geometry, the 2-year flow was found to be approximately 0.5 feet below the top of bank within the proposed crossing. Therefore, the design channel geometry based on the upstream design reach was not scaled, and the hydrology was increased a reasonable amount so that the 2-year WSE reached close to the top of bank in the proposed channel. This resulted in the design channel having a BFW of 5.8 feet. This is less than the average BFW of 7.4 used to size the MHO (Section 4.2.2). Accordingly, floodplain engagement will occur at 2-year and higher flows which will dissipate stream energy at higher flow events, reducing the risk of excessive scour and incision. The proposed channel shape will allow natural processes to continue within the proposed crossing and regrade area.

As noted in Section 2.7.2 some of the observed banks were nearly vertical while others sloped gradually. Accordingly, the proposed channel shape is a balance between matching the existing channel as best as possible given the limitations of uniform synthetic channel design and constructable slopes needing to be a maximum slope of 2H:1V. The channel planform and shape do not fully capture the variability that will result from the natural building material and complexity features discussed in Section 4.3.2. The generalized shape of the proposed channel geometry is a two-stage channel with a relatively flat 3-foot-wide channel bottom, which then slopes up at 2H:1V for 0.7 vertical feet resulting in a 5.8-foot top-of-bank width. The proposed bankfull channel is 0.9 feet deep and 5.8 feet wide, resulting in a width-to-depth ratio of 6.8.

The proposed bankfull channel connects to 20H:1V variable width floodplain benches on each side until it reaches the MHO width of 13 feet described in Section 4.2. Figure 44 shows the comparison of the proposed section with all the BFW measurement locations including the downstream ones. In the regraded channel outside the crossing, the edge of the MHO ties into the existing ground at a 2H:1V slope depending on the surrounding terrain. If the 2H:1V slope does not catch after approximately 8 vertical feet, the slope transitions to 1H:1V. The final tie-in slope above the active channel will be determined at a later design stage.

Channel complexity features such as large wood and streambed boulders will create planform variability in both the bankfull channel and thalweg by forcing localized changes in flow direction, turbulence, and scour within the proposed 13-foot-wide regraded channel. Complexity features which are the source of planform variability are discussed in Section 4.3.2. At a proposed slope of 4.7 percent, true geomorphic meanders are not expected in this channel type, nor were they part of this design. However, some degree of planform variability that mimics observed stream forcing features is part of the design planform and hydraulic modeling (Section 4.1.2). The variability intends to replicate observed forcing features (e.g., large wood or boulders). The 5.8-foot bankfull channel adjusts laterally around forcing features within the 13-foot-wide footprint (see Section 4.3.2 for an illustration and further discussion of complexity features). Achieving hydraulic diversity so fish can rest and swim through the proposed channel is a primary objective of the channel forcing, but the features are not geomorphic meanders, and a meander belt amplitude assessment was not considered.

To illustrate normal flow path and the effect of channel complexity features in the hydraulic model and conceptually convey the expected planform variability in the constructed channel, sinuosity was added to the proposed model channel surface. During construction, a low-flow channel will be built that connects habitat features together so that the proposed crossing is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field. For modeling purposes, the amplitude of the bankfull width channel sinuosity was designated at 2 feet, although it is expected that the actual constructed low-flow channel thalweg will shift to the outside edge of the bankfull channel and further increase the hydraulic and planform variability. Local scour around habitat features will alter the proposed channel shape over time, but the basic channel shape and planform is expected to be largely determined at the time of construction.

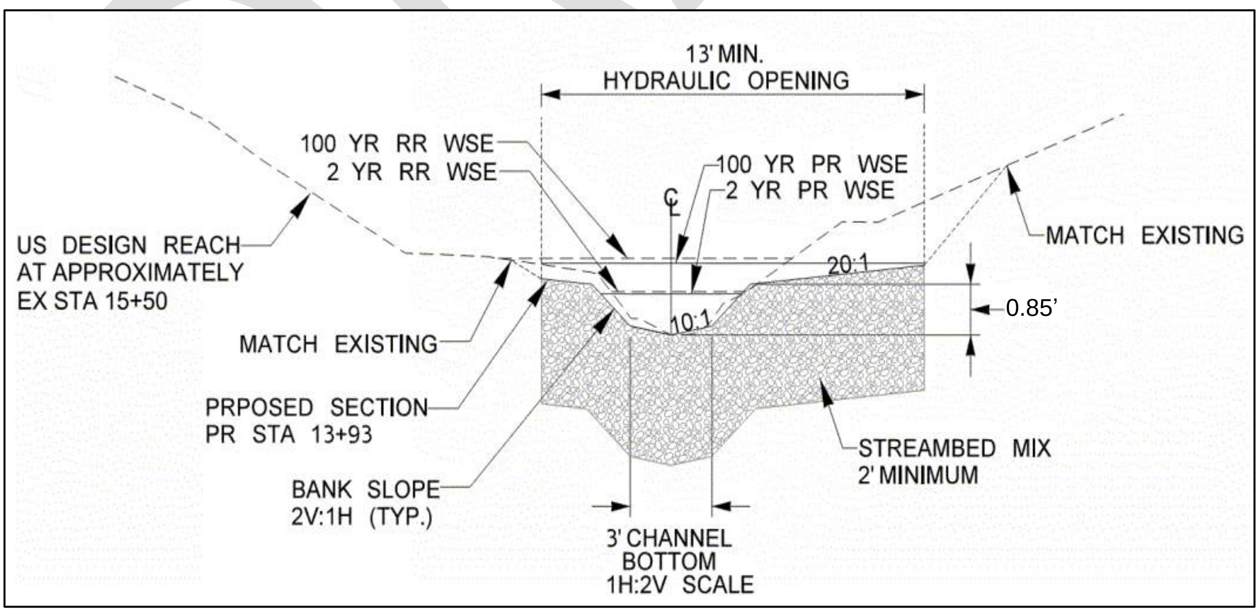

Figure 43. Design cross-section

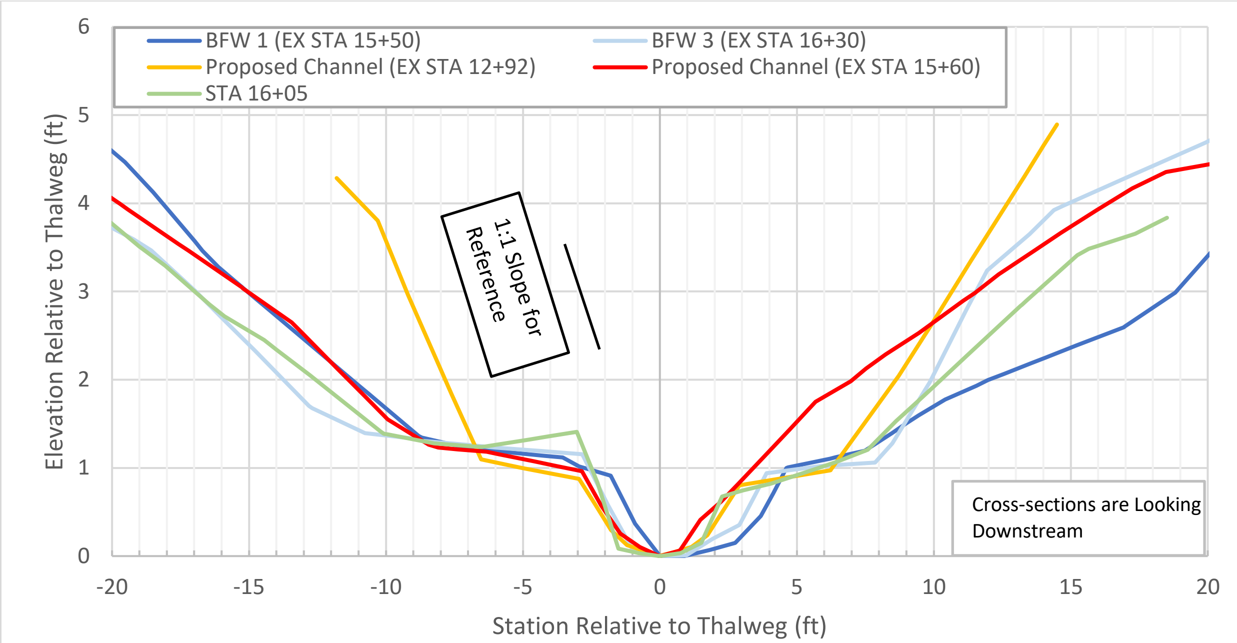

Figure 44. Proposed cross-section superimposed with existing survey cross-sections

4.1.2 Channel Alignment

The proposed alignment for UNT to Hood Canal at Crossing 991240 seeks to minimize the length of the structure and decrease the slope of the channel through the proposed crossing as much as possible. The total proposed length of stream channel regrade is 231 feet, with a crossing length of approximately 60.4 feet, depending on the final structure type and size. The proposed channel reconstruction begins just below the confluence of the main tributary and a smaller east branch tributary. The proposed alignment is shifted slightly east of the existing stream path so that the proposed crossing inlet is several feet east of the existing culvert inlet. This subtle shift lines the stream up to cross the highway more perpendicular which decreases the structure length. The proposed channel ties in 110 feet downstream of the existing culvert outlet and reconstructs what is currently an incised marginal channel effected by the culvert. The sinuosity ratio of the proposed channel matches the upstream design reach value of 1.1. The proposed alignment can be seen in Appendix D.

Sinuosity was added to the regraded channel by oscillating the thalweg and channel bank lines at a wavelength of approximately 52 feet and an amplitude of approximately 2 feet. The CAD surface creation technique holds the 13-foot hydraulic opening and floodplain regrade straight through the crossing following the proposed alignment. Then a secondary alignment only for the bankfull channel and thalweg meanders through the floodplain area, as a natural confined stream shifts its flow path within a ravine. The bankfull channel sinuosity is an approximation based on the spacing and size of habitat complexity features such LWM and proposed boulder clusters as discussed in Section 4.3.2.

4.1.3 Channel Gradient

The downstream design reach was used to inform the slope of the proposed crossing. As described in Section 2.7.1, the project crossing lies at a natural transition in the terrain slope. The average slope in the upstream design reach is 3.4 percent. The average slope in the

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downstream design reach is 4.6 percent. Closely matching the downstream design reach slope provides a relatively smooth transition to existing ground upstream while not requiring extensive addition regrade upstream. Having the transition slope upstream of the crossing also reduces the likelihood of a knickpoint forming downstream and propagating through the crossing.

The WCDG (Barnard, et al., 2013) requires the slope of the proposed channel be within 25 percent of the downstream reach and matches the overall slope of the natural stream. The average gradient in the reconstructed channel is 4.7 percent. The slope ratio of the proposed crossing slope compared to the downstream design reach (Section 2.7.1) slope of 4.6 percent is 1.0 (Figure 42). However, due to the crossing being at a transitional location in the watershed, the slope ratio between the proposed crossing and the 3.4 percent upstream design reach is 1.4, larger than suggested by the WCDG. As described above, it was determined to be safer for the long-term stability of the channel and structure to have this transition occur above the structure. This regrade slope reduces the estimated potential long-term degradation at the site by lowering the proposed channel crossing elevation. However, an estimated 4 feet of potential degradation was estimated to still be possible through this slope transition (see Section 7.2 for long-term degradation potential).

The proposed slope of 4.7 percent is the most conservative straight-line estimate of the slope and does not consider the increase in flow path length due to channel forcing and complexity features. The flow path along the proposed sinuous alignment is 4.6 percent (Appendix D, Sheet HY03). The meandering low-flow channel was designed to minimize the slope through the crossing as much as possible. Options for lengthening the channel reconstruction were examined and there is no appreciable decrease in slope by regrading the channel farther upstream or downstream. The regrade limits established also avoid disturbing existing LWM observed upstream and downstream of the tie-in locations. The upstream reach has a slightly lower slope than the proposed channel, but matching the steeper downstream reach slope more closely agrees with the intent of stream simulation methodology and reduces the risk of degradation through the crossing.

4.2 Minimum Hydraulic Opening

The MHO is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance. For discussion on the scour elevation see Section 7. See Figure 45 for an illustration of the MHO, hydraulic width, freeboard, and maintenance clearance terminology. The Structure-Free Zone (SFZ) is, at a minimum, the same as the MHO.

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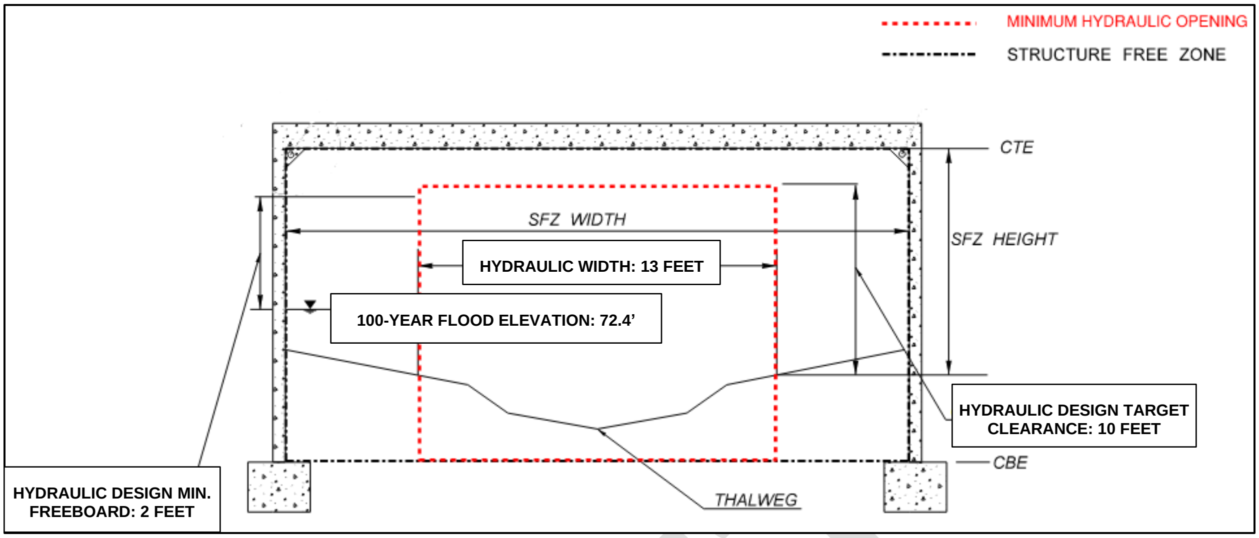

Figure 45. Minimum Hydraulic Opening illustration (Not to scale)

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard, et al., 2013) and the WSDOT *Hydraulics Manual* (WSDOT, 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the designed average BFW is less than 15 feet (Section 2.7.2), the channel is confined (Section 2.7.2.1), little or no channel movement is anticipated (Section 7.1), and the channel has at least moderate vertical stability (Section 2.7.4). The existing roadway elevation is 21.5 feet above the channel thalweg, providing sufficient vertical space for clearance and freeboard.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 11 feet was determined to be the minimum starting point. This is based on the DS design reach average BFW of 7.4 feet (Section 2.7.2) times 1.2 plus two feet which equals 10.9 feet, rounded up to 11 feet. To replicate the planform variability observed in the upstream reach the hydraulic width was increased by 2 feet to 13 feet. This creates a factor of safety of 1.2. The additional width will accommodate shifts in the channel while keeping the channel banks far enough away from the structure walls to avoid potential entrainment. In the proposed crossing, the 100-year flow contacts the edge of the hydraulic width to a height of 0.5 feet.

The proposed bankfull channel has a width of 5.8 feet (Section 4.1.1). This allows for 1.4- to 5.4-foot-wide overbank floodplains on either side of the bankfull channel. As described in Section 4.3.2, the channel and overbank area will have immobile complexity features which will create hydraulic complexity through the crossing and prevent flow entrainment along the structure wall.

Based on the factors described above, a minimum hydraulic width of 13 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The proposed-conditions model results in Section 5.4 show that the 13-foot hydraulic width creates similar conditions in the crossing compared to the upstream design reach of UNT to Hood Canal, which is one of the design goals of the stream simulation methodology.

Modeled 100-year velocities are slightly higher through the proposed structure than through the upstream design reach, which can be explained by the increase in channel slope. Velocities through the structure are less than the downstream design reach where the slope is slightly higher than in the crossing. As discussed in Section 2.7.5, the risk of lateral migration for the UNT to Hood Canal is limited by the confined nature of the stream and the valley in which it lies. The crossing is located at a transition reach with a steep-sided ravine with a large volume of overburden confining the channel on the downstream side of the crossing and severely limiting lateral movement. Likewise on the upstream side of the roadway the channel is well-entrenched in the terrain. The proposed preliminary 60-foot-long crossing is approximately 4.6 times the 13-foot-wide hydraulic width, which is significantly lower than the length-to-width ratio of 10 required for stream simulation. This length-to-width ratio does not warrant increasing the hydraulic width.

The projected 2080 100-year flow event was evaluated. Table 7 compares the velocities of the 100-year and projected 2080 100-year events.

Table 7. Velocity comparison for 13-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Downstream of structure (STA 12+71)	4.7	5.3
Through structure (STA 13+93)	3.7	4.0
Upstream of structure (STA 14+73)	4.0	4.1
Upstream design reach (STA 15+82)	3.5	4.1

No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8. The minimum required freeboard at the project location, based on bankfull width, is 1 foot above the 100-year WSE (WSDOT, 2022a; Barnard, et al., 2013)).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.4 feet for the 2080 projected 100-year flow rate at the upstream face of the structure (Table 8). The risks of aggradation or large debris build up are low for the project crossing and the minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience. The 100-year WSE within the proposed crossing at the upstream face is 74.0 feet, and the 2080 100-year WSE is 74.4 feet. The crown of the roadway is 92.3 feet. Due to the 18 feet of elevation difference, meeting freeboard requirements should not be an issue.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as large boulders or LWM. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 include boulders within the structure that may need to be maintained. Therefore, a maintenance clearance of 10 feet to allow for machinery to access and operate under the structure is required. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. Due to the elevation of the road, meeting maintenance clearance will not be an issue.

Table 8. Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	13+62	14+22
Thalweg elevation (ft)	69.5	72.3
Highest streambed ground elevation within hydraulic width (ft)	70.6	73.3
100-year WSE (ft)	70.9	73.7
2080 100-year WSE (ft)	71.1	73.9
Required freeboard (ft)	1.0	1.0
Required maintenance clearance (ft)	10	10
Required minimum low chord, 100-year WSE + freeboard (ft)	71.9	74.7
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	72.1	74.9
Required minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	80.6	83.3
Required minimum low chord (ft)	**80.6**	**83.3**

4.2.3.1 Past Maintenance Records

WSDOT Olympic Region Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of sedimentation or LWM racking at the inlet. The maintenance representative indicated that there was no record of LWM blockage and/or removal nor sediment removal at this crossing. As noted in Section 2.6.2, conversations with the downstream landowner revealed the downstream channel has been cleared periodically including the removal of LWM from the channel.

4.2.3.2 Wood and Sediment Supply

The current potential for LWM transport within the main channel in the proposed conditions is low (Section 2.6.4). This is due to both the size of the stream and its lack of power to move substantial amounts of debris, and also the 36-inch private driveway culvert located approximately 295 feet upstream of the project crossing (Figure 7). Were the driveway culvert to be removed in the future, the potential for LWM transport within the project reach would increase slightly. The project basin is largely undeveloped and is predominantly forested with maturing stands of evergreen owned and managed by the Washington State DNR (Section 2.2). It is expected that some natural recruitment of wood from the local and upstream riparian

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corridors will occur. The relatively low flow of the UNT to Hood Canal makes its capacity to transport LWM limited. Wood material that could be transported by the stream is likely to pass through the proposed MHO. Wood stability will be analyzed in later phases of the design (Section 4.3.2.2).

Aggradation is not expected to become chronic and accumulate, as the break in channel slope suggests there is more energetic potential for degradation (Section 2.7.4). Degradation will be driven by the slope transition from the milder upstream channel to the steeper downstream channel. The upstream culvert may act to limit sediment supply, which further supports the potential for degradation until it is removed. Cohesive glacial deposits are noted in the WSDOT preliminary geotechnical scoping report boring data from 18 feet to 43 feet deep (elevation 52 feet to 27 feet) (WSDOT Geotechnical Office, 2022). It is reasonable to assume the presence of cohesive glacial clay sediment might also act to limit the amount of channel incision (Section 7.2). The 10 feet of vertical clearance recommended is expected to be large enough to allow wood and sediment to be transported through the crossing (Section 4.2.3).

4.2.4 Hydraulic Length

A minimum hydraulic width of 13 feet is recommended up to a maximum hydraulic length of approximately 60.4 feet. If the hydraulic length is increased beyond 60 feet, the hydraulic width and vertical clearance will need to be reevaluated.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 3 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics or the project office. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design and features developed for UNT to Hood Canal at SR 3 MP 58.21.

4.3.1 Bed Material

Stream simulation methodology aims to replicate natural stream sediment within the proposed crossing (Barnard, et al., 2013; WSDOT, 2022a). To match the observed streambed sediment, the WSDOT Hydraulics Manual recommends using the stream simulation requirement of a proposed D_{50} within 20 percent of the D_{50} in the reference reach, unless prevented by contraints. Examples of constraints include situations where the reference reach is sediment starved, adjacent to infrastructure, or the stream is in a state of alteration (WSDOT, 2022a). For the project crossing an existing private upstream culvert (Figure 13) acts as a constraint limiting natural sediment transport, most notably of the larger bedload size particles. The proposed sediment design is intended to meet stream simulation requirements while also providing the surface roughness required for a channel of this size and slope.

A comparison of average sediment sizes observed in the design reaches and proposed sediment sizes is provided in Table 9. WSDOT requires the streambed to be sealed with streambed fine sediment that can pass a #4 sieve during construction, adding additional streambed fines to the stream during construction. A comparison of the existing, proposed, and stable Bathurst gradations along with a well-graded Fuller-Thompson gradation shows the proposed mix closely tracks pebble count results and meets the stream simulation criteria (Figure 46Figure 43).

Table 9. Comparison of observed and proposed streambed material

Sediment size	Proposed diameter (in)	Pebble count sediment diameter (in)
D_{16}	0.03	0.2
D_{50}	0.8	0.7
D_{84}	2.3	1.3
D_{95}	5.4	2.5
D_{100}	12.0	8.9

The Unit-Discharge Bed Design approach was used to inform the sediment sizing for the UNT to Hood Canal. The WSDOT Hydraulics Manual recommends two approaches for sediment mobility analysis for the proposed sediment mix: the Modified Critical Shear Stress approach for systems with slopes less than 4.0 percent, and the Unit-Discharge Bed Design approach (hereafter referred to as the “Bathurst method”) for systems with slopes greater than 4.0 percent (WSDOT, 2022a). Both approaches were examined for this project since the proposed sinuous channel gradient is 4.6 percent (Section 4.1.3).

The Bathurst method is applicable for steeper channels where flow depth is more variable due to the presence of large rocks or woody debris that cause flow depth to change rapidly (USFS, 2008). The UNT to Hood Canal is a small stream and, in both the observed and proposed conditions, LWM and boulders create hydraulic depth variability. Therefore, the Bathurst method was considered the most appropriate method for this project. The Bathurst method calculates a stable D_{84} for a channel based on slope, 100-year flow, and bankfull channel width (Figure 46).

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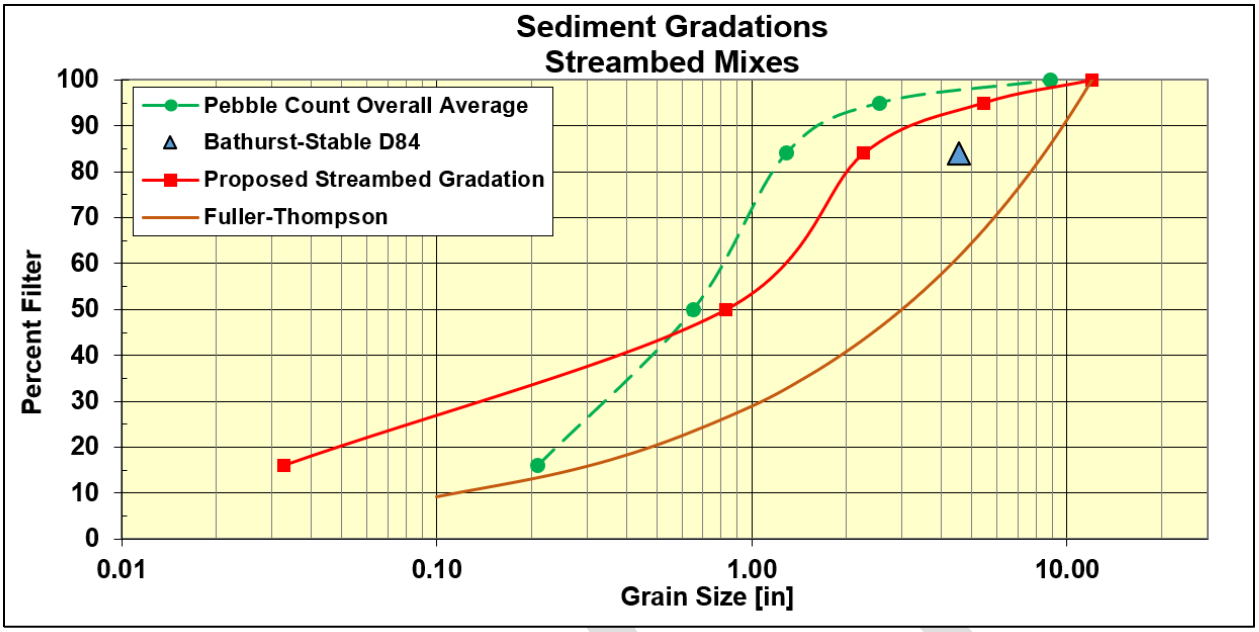

Figure 46. Existing and proposed streambed gradation comparisons

The crossing is in a transitional reach with a proposed slope slightly steeper than the existing upstream slope. The difference between upstream and downstream pebble count data was not significant and, thus, the proposed streambed mix was based on both upstream and downstream pebble counts, with the exception of Pebble Count #2 upstream which was excluded because it was taken at a muddy bench that is not representative of the overall stream morphology (Section 2.7.3).

The streambed design mix is composed of 90 percent Streambed Sediment (WSDOT Standard Specification 9-03.11(1)) and 10 percent 12-inch Cobble Mix (WSDOT Standard Specifications 9-03.11(2)) (WSDOT, 2022b). The proposed sediment mix closely matches the pebble count data. The small percentage of cobbles in the proposed sediment design mix does not create a stable mix, but any increase the percentage of cobbles increases the proposed D_{50} of 0.8 inches which take the mix outside of 20 percent the pebble count D_{50} of 0.7 inches. The proposed sediment gradation D_{84} is 2.3 inches which is an inch larger than the pebble count average D_{84} of 1.3 inches, but considerably less than the Bathurst unit discharge calculated stable D_{84} for the channel of 4.5 inches. The minor shift in the proposed D_{84} is warranted by the upstream driveway culvert constraint, slope, and observations of recent reach scale incision observed at the site.

An undersized driveway culvert approximately 295 feet upstream of the project crossing likely does not significantly alter the volume of sand and suspended sediment in the stream, it is likely to alter gravel and larger size bedload sediment transport. While some bedload sediment from the intervening section of stream between the upstream driveway and project site will reach the proposed crossing, given the proximity and number of stream crossings in the watershed, an overall purely natural sediment regime is not expected at the project site. The observed evidence of recent incision and bank erosion during the site visits supports the conclusion that stream stability should be considered to some degree for the site. The proposed gradation is not intended to be stable, and stability analysis suggests this is not a stable mix, but rather the gradation is intended to not completely mobilize during typical high-water event.

The streambed design sediment mix is proposed throughout the reconstructed channel including floodplain areas. In addition to the streambed sediment, LWM, small wood, and slash are proposed in the reconstructed channel and will provide hydraulic complexity as well as stable roughness that promotes sediment retention. Habitat complexity features are described in greater detail in the following section.

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Hood Canal at SR 3 MP 58.21.

4.3.2.1 Design Concept

The proposed channel design will mimic the design reach, creating a single-thread two-stage channel. LWM will be placed at specific locations outside of the crossing structure to develop channel complexity throughout the reconstructed channel. Wood will be placed in a roughly alternating pattern to keep the low-flow channel unobstructed (Figure 47). The function of the LWM is to enhance habitat in the proposed channel by forming scour pools, providing cover, adding organic material and a source of food, contributing to hydraulic diversity, and encouraging gravel deposition. A small number of deliberately placed preformed pools should be considered during final stream design with consideration for connecting any pools with a low-flow channel to prevent fish becoming stranded.

The proposed slope of 4.6 percent is fairly steep and, while streams of this slope are often classified as step-pool systems, no prominent steps were observed in either of the design reaches, including downstream of the crossing where the existing channel average slope is 4.6 percent. Instead, the channel consists of long riffles or rapid segments followed by calmer glides.

The lack of steps can be attributed to the small size of the stream and lack of power to force the largest bed material into step features. It is also possible that the recent incision observed downstream could be covering some small boulders steps with the recent influx of bank material. The energy of a stream is dissipated largely through turbulence created by surface roughness. The observed stream relies on the high relative roughness provided by exposed boulders and wood debris in the stream to dissipate energy throughout the channel rather than at discrete steps. Mimicking the observed conditions, the proposed stream design concept relies on providing stable roughness features and forcing channel irregularity with LWM and boulders all along the channel rather than proposing steps. It is important that the same or a similar level of roughness is created inside the crossing as exists naturally. If the channel roughness and the energy of the flow are not in balance the channel will change shape by eroding and widening until the flow becomes shallow (plane bed) and the sediment left creates enough roughness relative to flow depth to absorb the flows energy.

WSDOT has provided guidance and analysis tools for LWM quantities consistent with A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State (Fox & Bolton, 2007). There are three metrics representing the LWM quantities observed by Fox and Bolton: density of key pieces, total wood pieces, and total wood volume. The percentile targets are determined by habitat zone and bankfull width class. The UNT to Hood Canal is in the Western Washington habitat zone and the design shape of the channel has a BFW of 5.8 feet (Table 3). The metric targets for the project site are listed below:

- 0.03 key piece per foot of stream; each key piece must meet minimum volume of 1.31 cubic yards excluding the rootwad.
- 0.12 total wood pieces of LWM per foot of stream.
- 0.39 cubic feet of total wood volume per foot of stream.

The key piece density requirement and total number of LWM pieces in the Fox and Bolton (2007) metrics described above were used as the targets for the proposed LWM design. The minimums required for each metric are based on the total stream reconstruction length of 231 feet. The regrade length for determining quantities includes approximately 60 feet covered by the crossing structure where only two mobile logs will be placed. The target numbers for LWM are shown in Table 10. See Appendix F for details on the calculations.

Table 10. LWM log metrics (Fox & Bolton, 2007)

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	8	38	39.1
75% Targets	8	27	91.2
50% Targets	4	20	47.0

The proposed design surpasses the 75th percentile targets for number of key pieces and total number of LWM pieces. The proposed LWM layout maximizes the regraded channel area outside the crossing structures but is not able to meet the 75th percentile target for total LWM volume due to the relatively small size of the stream. In order to meeting the 75th percentile target for total volume, LWM would have to be placed outside of the 100-year flow extent, which would negate any significant habitat or hydraulic benefit.

The design proposes eight key pieces (labeled as Type 1 log in Figure 47) that each meets the minimum volume of 1.31 cubic yards. The proposed key pieces are 2 feet in diameter at midpoint and 25 feet long. In addition to the 8 key pieces, the design includes 30 non-key pieces. Of the non-key pieces, 7 are 1.5 feet in diameter at midpoint and 20 feet long with rootwad (labeled as Type 2 log in Figure 47). The rest of the non-key pieces are smaller, 1 foot in diameter at midpoint and 10 feet long with rootwad, to provide smaller woody debris in the channel (labeled as Type 3 log in Figure 47). The LWM layout design proposes a total of 38 LWM pieces and a total wood volume of 39.1 cubic yards. See the proposed LWM layout in Figure 47. The LWM layout is conceptual and does not show how individual pieces are embedded, vertically angled, or how exactly they might interact with the channel banks.

The LWM pieces were placed to not block the low-flow channel, but at the same time still engage with it. Smaller Type 3 pieces are not proposed directly upstream of the crossing to avoid partially blocking the structure. The key LWM piece placed near the structure entrance is placed parallel to flow and just upstream of the left wingwall to avoid deflecting flow toward the opposite edge of the crossing. Anchoring is not anticipated in small stream such as the UNT, but LWM stability calculations were not completed as part of the layout. These stability calculations will be developed in a later stage of design where the need for anchors or vertical post along with the risk of wood rotation will be fully considered, and the wood layout reevaluated.

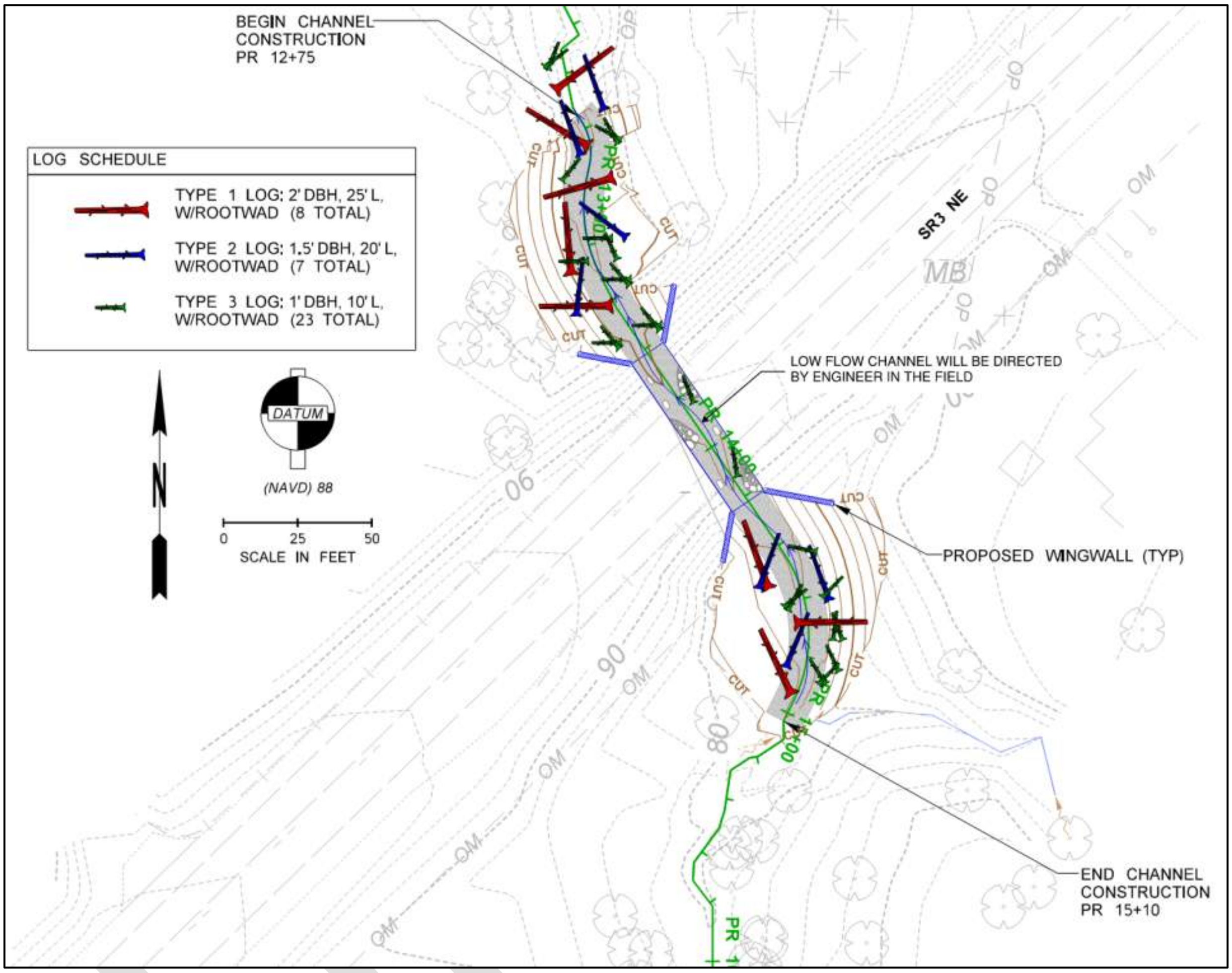

Figure 47. Conceptual layout of large wood material

LWM is not proposed within the crossing structure. The proposed complexity features within the preliminary 60-foot structure include Type Two Streambed Boulders (WSDOT Standard Specifications 9-03.11(3)) (WSDOT, 2022b), and partially buried small wood which ideally provide a similar hydraulic effect to LWM. Like the LWM, streambed boulders can cause flow deflection and turbulence, increasing hydraulic complexity and sediment retention within the crossing structure. The boulder and small wood within the crossing structure are a critical part of forming a stable and hydraulicly diverse channel with areas of velocity refuges in the steep channel. Because the proposed structure is likely too small for LWM to be place in the crossing, the proposed boulders and small partially buried small wood are the only tools available to help mimic the steep, near-vertical banks observed in the design reach. Small wood within the crossing should be embedded to promote stability and sufficiently dense to compensate for the lack of LWM within the proposed culvert.

Rough stable banks are especially critical in a crossing structure where vegetation cannot develop due to a lack of sunlight. The WCDG states how important it is to define the channel shape and to use the stream margins to create juvenile migration pathways where turbulence and lower velocities occur. The proposed boulder clusters and partially buried small wood is intended to help accomplish that by creating velocity breaks along the channel margins and a longer flow path as the channel is forced to adjust around isolated stable boulders. By dissipating the stream's energy and creating turbulence the complexity feature keeping normal flows from winnowing away fines in the bankfull channel. It is recommended some of the proposed streambed boulders be placed in clusters along the channel banks while others are be placed individually in a manner to best facilitate planform variability and prevent flow from entraining against the structure walls.

The boulders are intended to be stable at all flow events. A conceptual layout of banks and crossing complexity features including boulder clusters is shown in shown in Figure 48. The figure is for illustrative purposes only; it is not drawn to scale and should not be considered a construction detail. The layout has most, but not all, of the rougher features along the banks or in the overbank areas. The exact size and density of the features within the structure will be confirmed in the final stage of design.

On February 16th, 2023, in a pre-submittal meeting comanagers asked for more precision in the number of boulders in the crossing and expressed concerns of over-coarsening the stream. It is worth noting the counterintuitive nature boulders as complexity features can play in a stream design. As described in Section 4.3.1 the proposed streambed sediment is mostly mobile. If no complexity features were placed in the proposed crossing, and the crossing channel was composed of only a trapezoidal channel of the proposed streambed sediment the crossing would act, as many do, like a smooth featureless flume. The increased velocity in the crossing would mobilize all but the largest sediment eroding the banks and bed, creating an armored over coarsened channel with a higher likelihood of subsurface flow that could be a barrier to fish during lower flows. By adding complexity features that absorb energy, create turbulence, and decrease velocity. The channel is more likely to sort sediment, retain fines, and not armor. Because boulders are the primary complexity feature allowed inside the crossing, adding a relatively small number of large stable boulders is the best option for preventing the exact over coarsening that is the primary concern expressed by comanagers about boulders.

The preliminary recommended number of channel complexity boulders is based on providing a similar amount of surface roughness to the channel in the crossing as the LWM does outside the crossing, to the extent possible noting that boulders inherently do not have the same roughness characteristics as LWM. The estimated total area of wood in the proposed channel is estimated at a minimum to be 10 percent of the floodplain area. If each 18-to-28-inch boulder is embedded approximately 70 percent, it is conservatively estimated 1.5 square feet of each boulder might be exposed within the minimum hydraulic width. 20 to 30 boulders at the surface inside the crossing would take up about 8 percent of the crossing surface area, which would put the complexity features inside the crossing close to although not the same amount of LWM complexity features outside the crossing. It is recommended some additional boulders, approximately half as many, are buried and unexposed. The proposed concept would create less than one boulder every 2 linear feet of a minimum 13' wide crossing, well within the density and spacing of boulders observed within the downstream reach. This density of the boulders will not form channel spanning features and would act against over coarsening the channel.

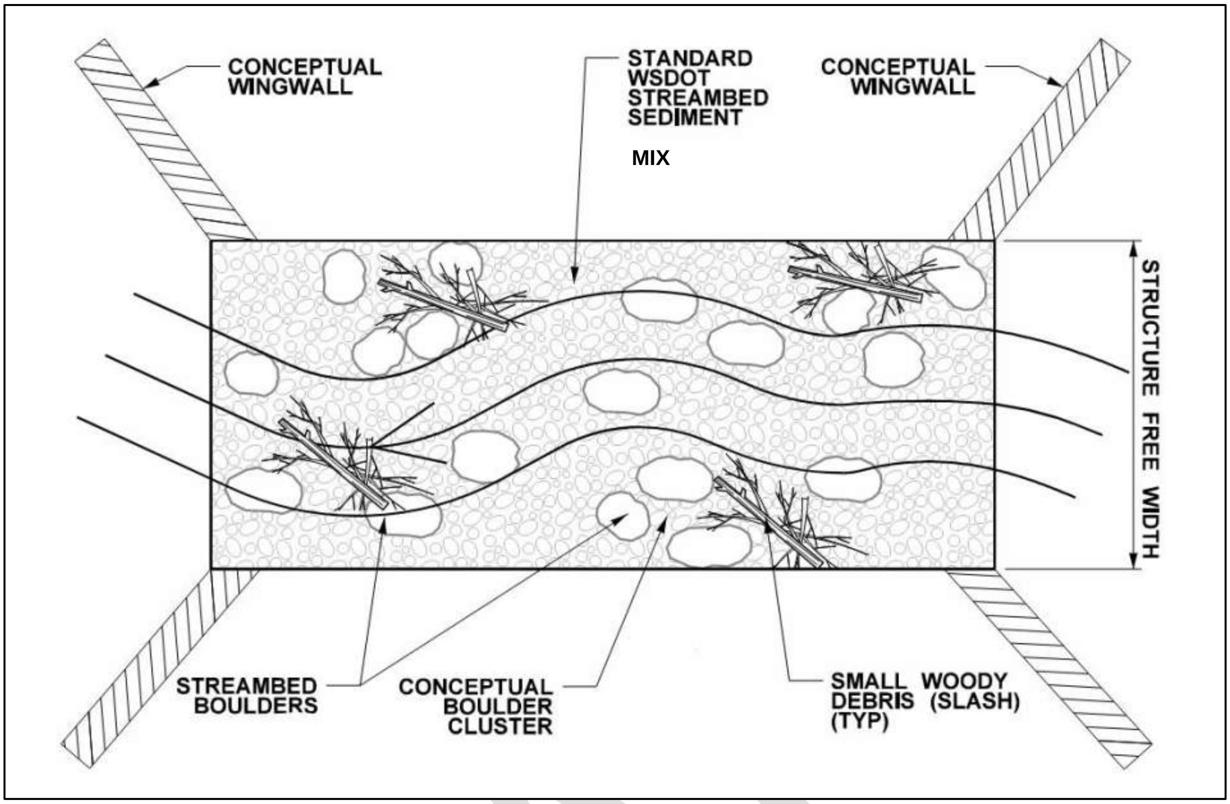

Figure 48. Conceptual layout of crossing complexity features

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed during final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 3 UNT to Hood Canal crossing was performed using the United States Bureau of Reclamation's (USBR) SRH-2D™ Version 3.3.0 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR, 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.15 (Aquaveo, 2021).

Two scenarios were analyzed for determining stream characteristics for the UNT to Hood Canal with the SRH-2D models: (1) existing conditions with the 2-foot-diameter concrete culvert, and (2) proposed conditions with the 13-foot-wide MHO.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

Channel geometry data (surface) was obtained from the MicroStation InRoads® files supplied by the WSDOT Project Engineer's Office (PEO), which was developed from topographic surveys performed by WSDOT on August 31, 2021. The survey extent was adequate to capture all essential structures and streambed elements, so no LiDAR was used. The proposed surface was developed from the proposed grading surface created by InRoads. All survey information is referenced against the North American Vertical Datum of 1988 (NAVD88).

5.1.2 Model Extent and Computational Mesh

The downstream model domain encompasses approximately 320 feet of the channel northwest of the SR 3 crossing. The upstream model extends southeast of SR 3 approximately 270 feet. These boundary conditions at the upstream and downstream ends of the mesh are far enough from the crossing to ensure modeling results are note influenced. The upstream boundary was placed just below the culvert crossing Scenic Drive NE at EX STA 17+99 to eliminate addition model work that does not provide significantly beneficial results.

The mesh developed for the existing-conditions hydraulic model has an area of 80,736 square feet and contains 23,292 elements (Figure 49). The proposed condition is comprised of the same area and 18,146 elements. The mesh developed for the future-conditions hydraulic model has the existing culvert area replaced with the proposed channel using quadrilateral elements (Figure 50). These quadrilateral elements were also used to represent uniform regions including the existing and proposed channels and the SR 3 roadway surface. Transitions and bends within the existing and proposed stream channel are represented by triangle mesh elements which better capture flow in multiple directions. The floodplain and forested areas are also represented by triangular mesh elements.

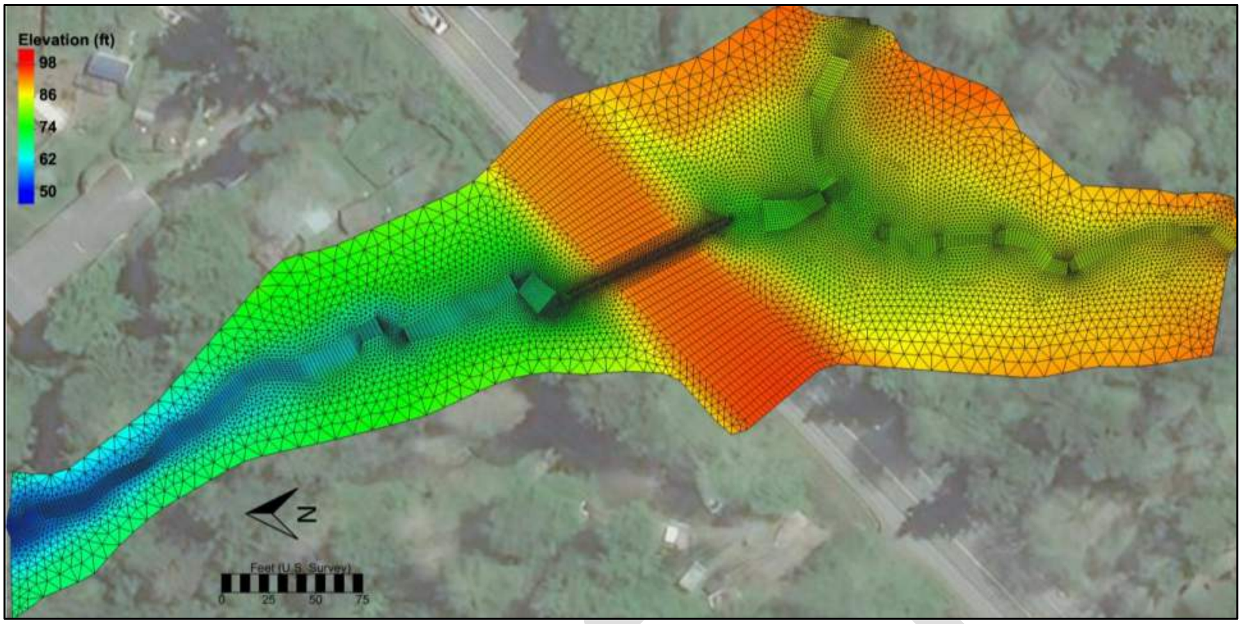

Figure 49. Existing-conditions computational mesh with underlying terrain

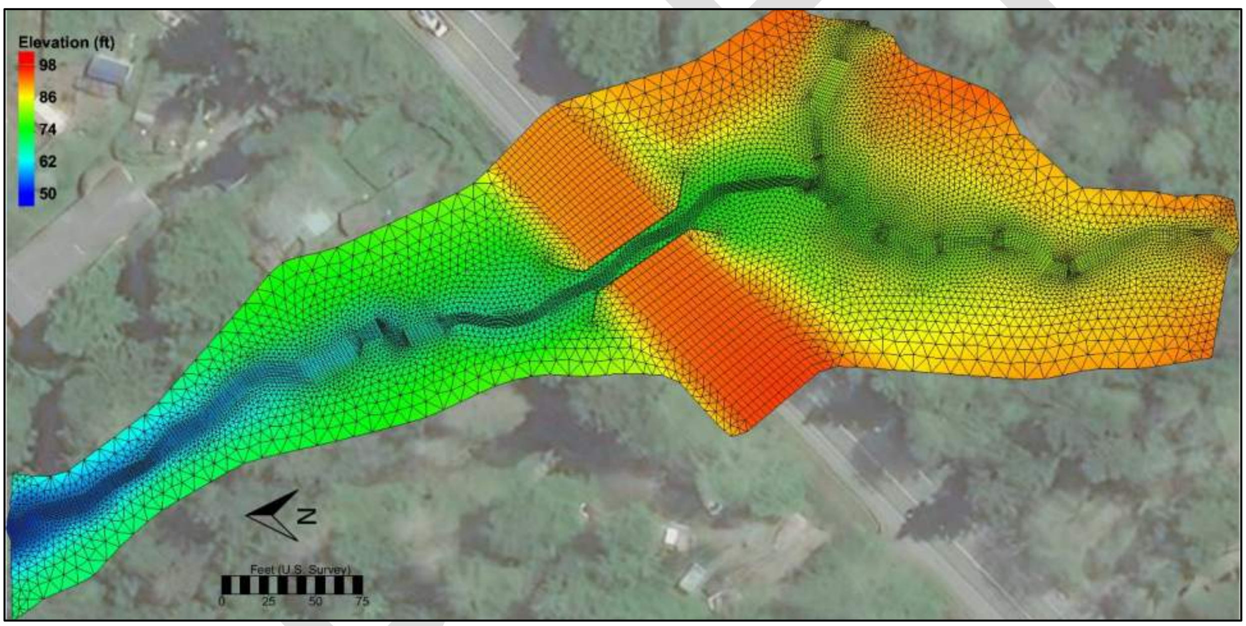

Figure 50. Proposed-conditions computational mesh with underlying terrain

Channel sinuosity generated from complexity features has been built into the proposed channel surface (Figure 50). Wingwalls of the proposed structure were also built into the survey surface and distinguished by closer node spacing along transitional features. Habitat features were represented as a compound roughness throughout the regions they occupy. This is most clearly evident in the Proposed Crossing Floodplain and the Proposed Channel Floodplain (Figure 51).

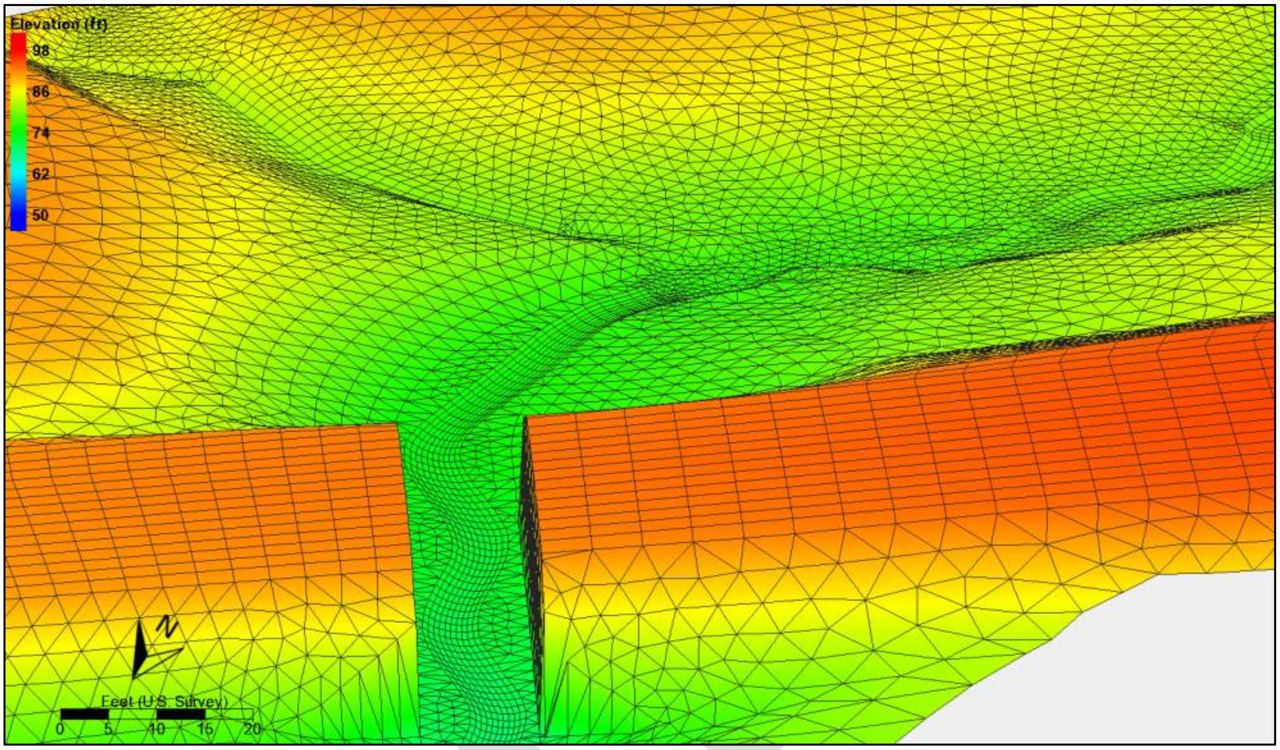

Figure 51. Proposed Mesh view of east tributary confluence

5.1.3 Materials/Roughness

Hydraulic roughness in the SRH-2D model is represented by Manning's n values. These composite values average the roughness within each coverage region. The existing and proposed model roughness conditions are divided into seven categories: Existing Main Channel, Existing Floodplain, Proposed Channel, Proposed Floodplain, Proposed Crossing Floodplain, Forest, and Roadway Table 11. Channel values were selected by using the U.S. Forest Service's Stream Channel Flow Resistance Coefficient Computation Tool (the spreadsheet tool) (Yochum, 2018). The spreadsheet tool combined tabular, semi-quantitative, and fully quantitative estimates. This tool averages tabular estimates to provide an overall average roughness value. Floodplain values came directly from tabular guidance from the WSDOT Hydraulics Manual (WSDOT, 2022a). Tabular values with descriptions matching the field observations in Section 2 were chosen.

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Figure 52. Spatial distribution of existing-conditions roughness values in SRH-2D model

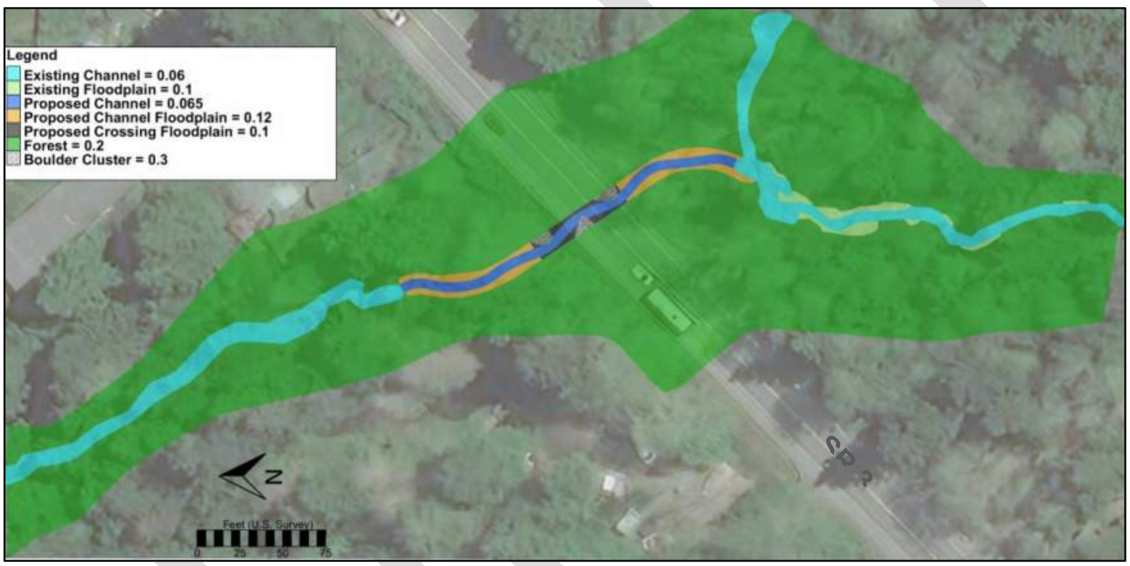

Figure 53. Spatial distribution of proposed-conditions roughness values in SRH-2D model

Some natural LWM downstream of the crossing has been removed by property landowners. This reduces the natural roughness of the downstream main channel and floodplain. The lack of a floodplain roughness region in the downstream reach accounts for this condition.

- **Existing Main Channel:** The Manning's n value of 0.06 is assigned to the Existing Main Channel based on the overall average results from the spreadsheet tool. The term "main channel" could also be described as the bankfull channel, and it the primary flow path for the single thread stream. The Hydraulics Manual description of mountain streams with gravel, cobbles, and few boulders best fits the Existing Main Channel. The tabular value of 0.05 was increased by 0.01 to account for brush and branches in the channel. The degree of irregularity, effect of obstructions, etc., were taken into account by the Arcement and Scheider method (Arcement, 1989). The hydraulic radius and mean flow depth were also considered by using Bathurst's, Jarret's, and Limerinos' quantitative methods. The spreadsheet tool averaged all the estimates into an overall value of 0.06 (Appendix E).

- **Existing Floodplain:** The Existing Floodplain value of 0.12 was chosen from the Hydraulic Manual (WSDOT, 2022a). This value is based on medium to dense brush. This brush along with natural wood debris can be observed in existing site photos (Figure 11 and Figure 18). This value is applied to the inundation extent of 100-year flow.
- **Existing Culvert:** The standard HY-8 value of 0.012 for a concrete culvert was used.
- **Proposed Channel:** The Proposed Channel value of 0.065 was generated by increasing the existing channel value by 0.005 to account for additional hydraulic obstructions caused by installed LWM placed outside of the crossing structure and smaller woody debris (slash) and boulders placed inside of the crossing.
- **Proposed Channel Floodplain:** The Proposed Floodplain will have significant LWM and should have similar vegetation to the Existing Floodplain. The Existing Floodplain value of 0.12 was deemed appropriate as the Existing and Proposed Floodplain should have similar roughness once vegetation is established.
- **Proposed Crossing Floodplain:** The value of 0.1 was selected by lowering the Proposed Channel Floodplain value by 0.02 to account for reduction in vegetation and LWM within proposed crossing structure floodplain.
- **Forest:** The roughness value of 0.2 from photographic guidance from the United States Department of Agriculture (Appendix E).
- **Road:** The Manning's n value of 0.016 for the road is chosen from Open Channel Hydraulics for rough asphalt (Chow, 1959). The roughness value for road is assigned in case SR 3 is overtopped.

Table 11. Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Existing Channel	0.06
Existing Floodplain	0.12
Proposed Channel	0.065
Proposed Channel Floodplain	0.12
Proposed Crossing Floodplain	0.1
Forest	0.2
Roadway	0.016
Concrete Culvert	0.012

5.1.4 Boundary Conditions

Both the existing and proposed conditions models are simulated using a steady flow regime. The model inflow boundary condition is a subcritical inflow at the upstream end of the model extent. The existing 2-year, 100-year and 500-year flows were run for 1, 4, and 10 hours, respectively. Larger flows were run longer due to extensive backwater inundation upstream of the culvert. The proposed condition 2-year, 100-year, 500-year, and 2080 100-year flows converged after 1 hour. The flows used are summarized in the Table 6 of Section 3. The distribution setting at the inlet is conveyance.

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The existing 2-foot-diameter culvert is simulated using HY-8 extension (Aquaveo, 2019) through boundary conditions in SMS (Aquaveo, 2021) in the existing-conditions model. The input parameters can be found in Table 11. This information is from the survey data delivered by the WSDOT survey team in August 2021. The standard HY-8 Manning's n value of 0.012 for a concrete pipe was used. The remaining parameters are shown in Figure 54.

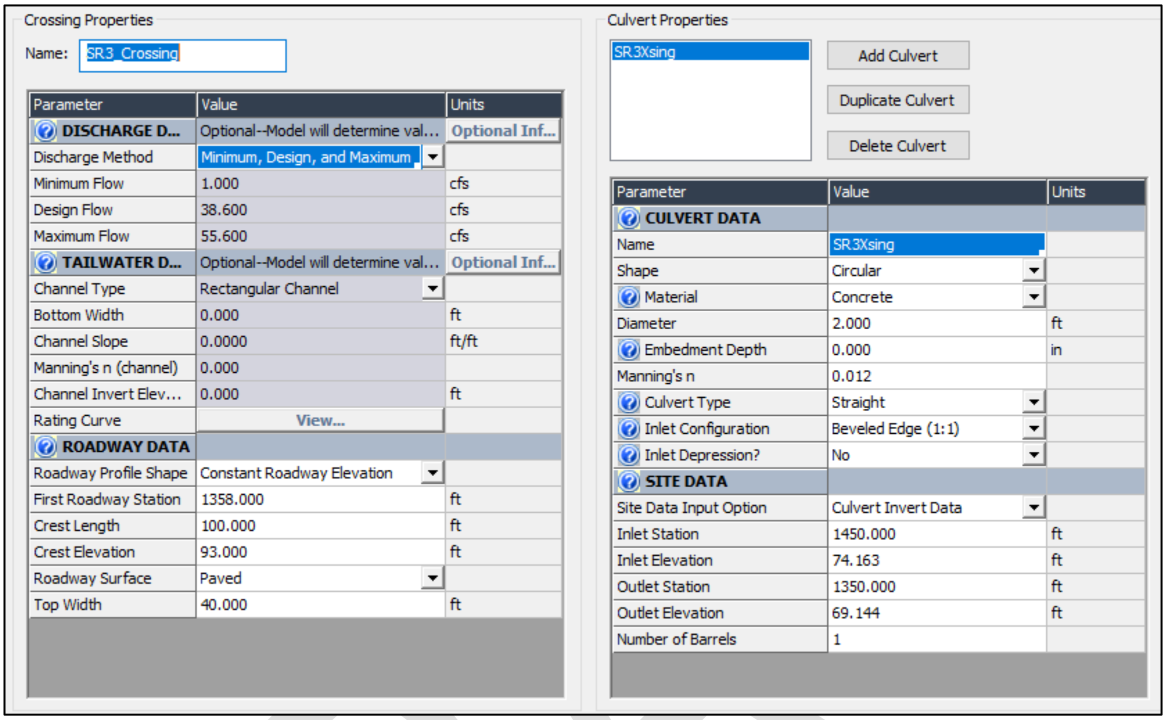

Figure 54. HY-8 culvert parameters

The exit boundary condition is a subcritical outflow using a rating curve calculated through the normal depth equation (Figure 55). The slope value is 0.06. This slope is measured over approximately the last 30 feet of the stream before water exits the model. The Manning's n value is 0.06. This is the roughness defined for the main channel in Section 5.1.3. The maximum flow is set at 55.6 cfs.

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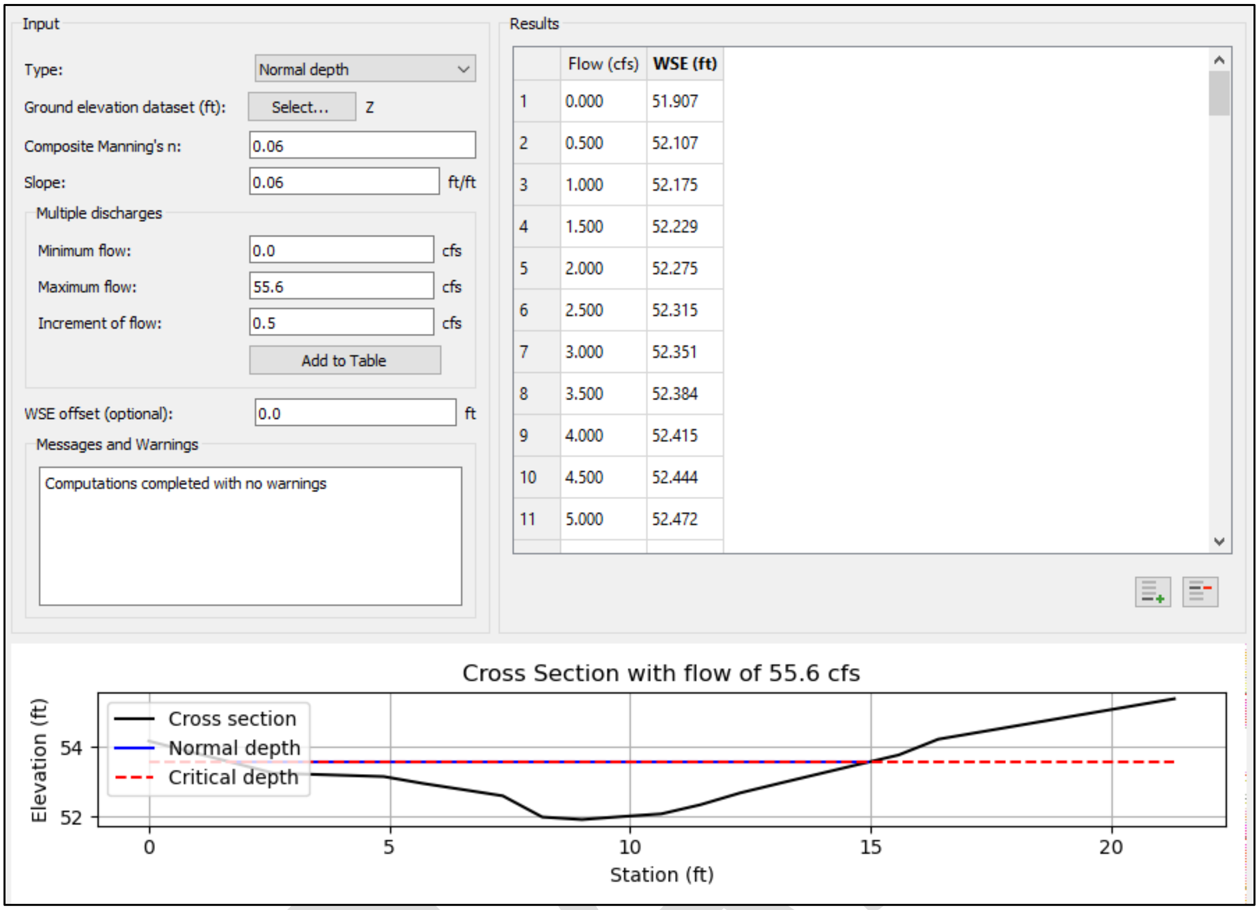

Figure 55. Downstream 100-year boundary condition parameters

The downstream rating curve is shown in Figure 56. This boundary condition was used in both the existing and proposed-conditions models. The locations of the boundary conditions in the existing and proposed-conditions model are shown in Figure 57 and Figure 58 respectively.

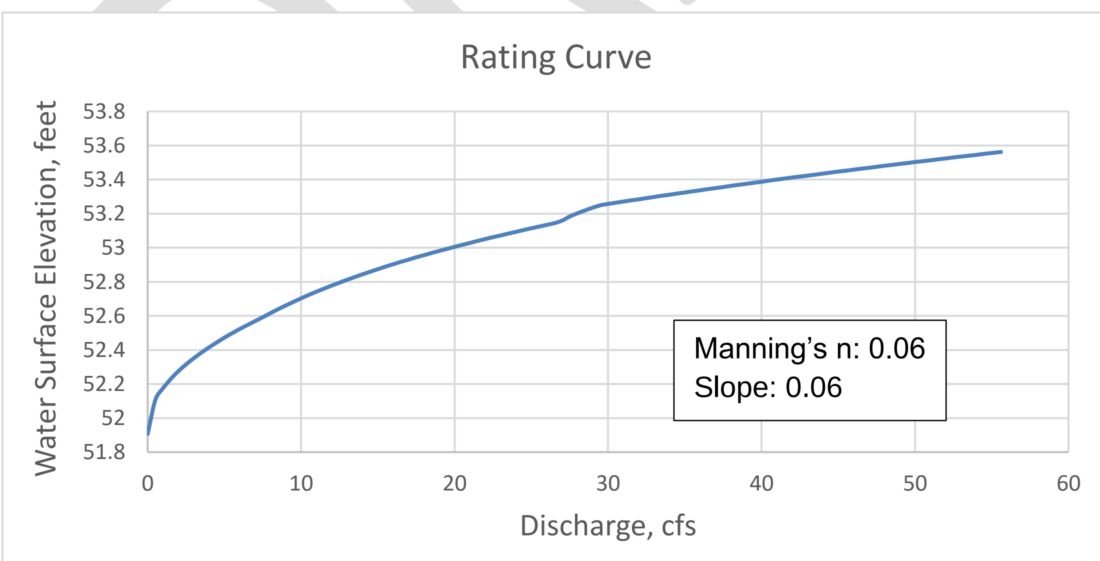

Figure 56. Downstream outflow boundary condition normal depth rating curve

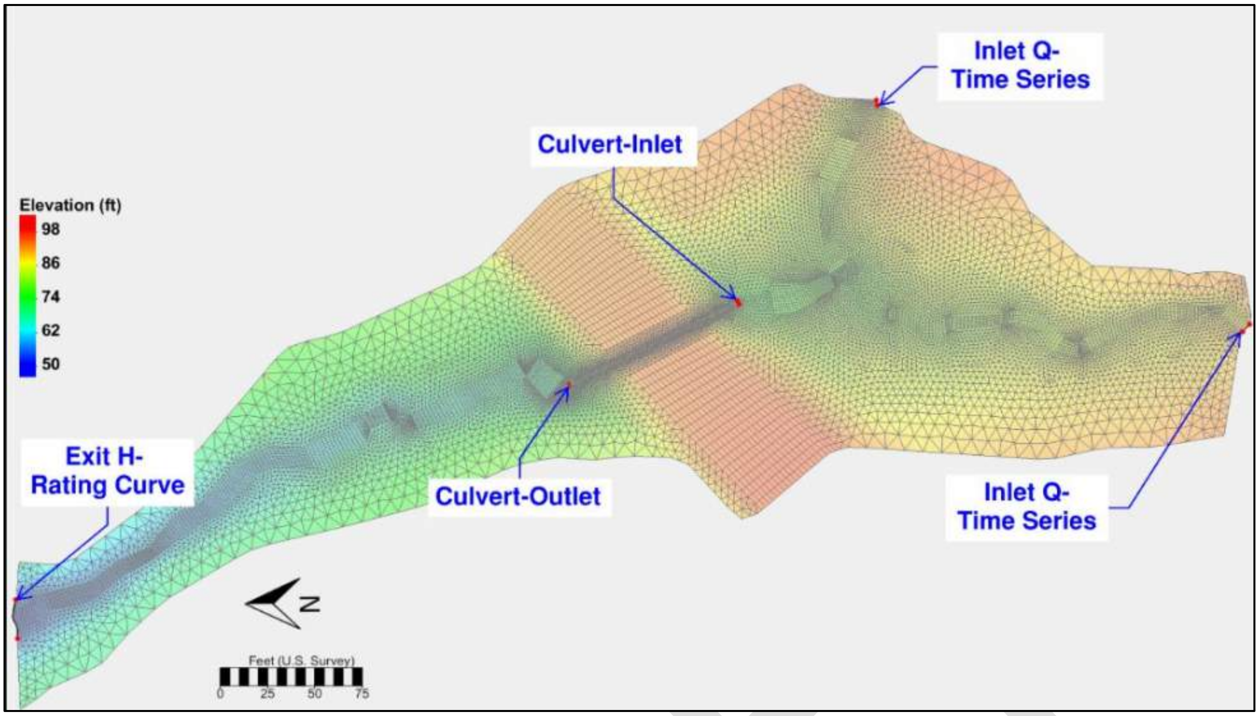

Figure 57. Existing-conditions boundary conditions

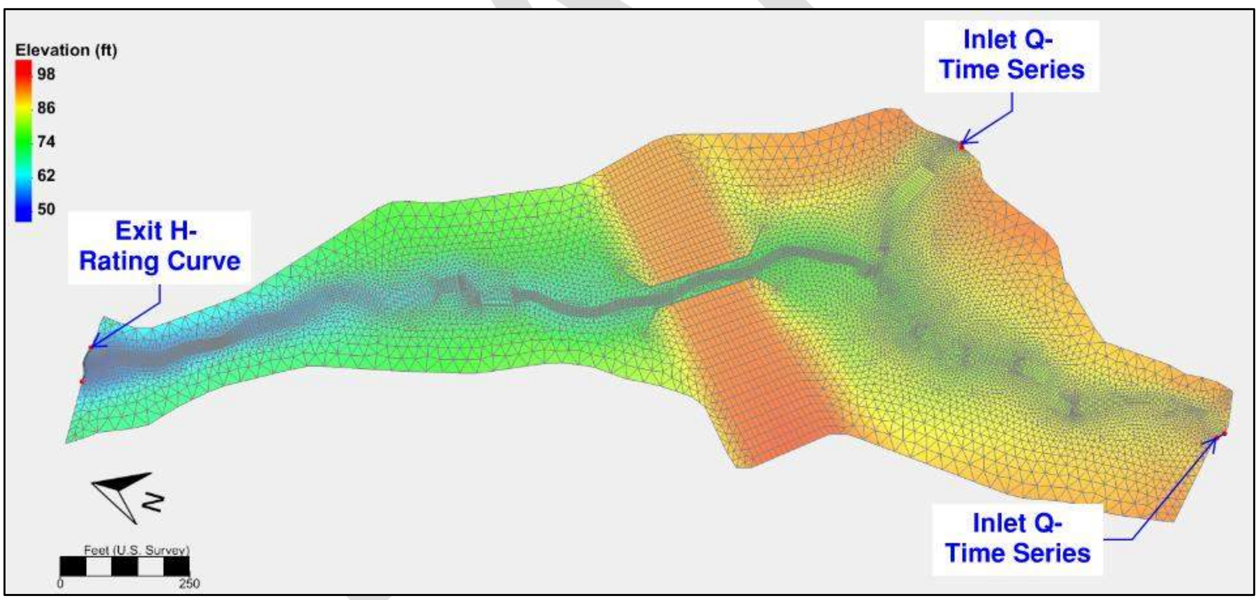

Figure 58. Proposed-conditions boundary conditions

5.1.5 Model Run Controls

Three peak flows were simulated in the existing-conditions SRH-2D model: the 2-year flow, 100-year flow, and 500-year flow (Table 6). The 2-year and 100-year flows were run for one-hour time segments. The 500-year and 2080 100-year flows were run for three-hour segments so that convergence was reached.

The future conditions model simulated the 2-year, 100-year, 500-year, and 2080 100-year flow. The extra runtime was required for the higher flows because of significant backwater and flooding that occurred at those flows. The total runtime was eight hours. The model was set up to run with an initial dry condition and a 0.5-second computational timestep. Results were output every 0.25 hours. For consistency, the existing and proposed models were run with identical run times and timesteps.

Both models were checked using PACE's QC checklist. This checklist covers mesh quality, boundary condition and material coverage inputs and examined model results with high shear stress and Froude numbers.

5.1.6 Model Assumptions and Limitations

The complexity of small-scale hydraulics which form around LWM and boulders are not perfectly simulated in the SRH-2D model. These micro-scale hydraulics are beyond the scope of the PHD investigation and require different analysis techniques and software with the capacity to model three dimensional flow. Regions in the model that include LWM and boulder are assigned compound Manning's roughness values which resulting in higher shear stresses and lower velocities. In reality, the complex physical processes are generating eddies, creating scour holes and partitioning shear stress within the water column to reduce velocity and sediment mobility. Although the SRH-2D model does not precisely simulate these micro-scale hydraulics and physical processes, the simulations do approximate their effects to the extent that the computed results provide useful data necessary to inform the hydraulic design.

The second limitation of the model is the shape of the complexity features. The proposed complexity feature shapes are roughly built into the mesh through InRoads template using curves with 52-foot wavelengths. Although the model surface has perfectly uniform sinuous shape as shown in Figure 48, the actual constructed geometry of the channel will be more varied and less symmetrical.

5.2 Existing Conditions

The 2-, 100-, and 500-year peak flow events were simulated in the existing-conditions model. Inundation and flow characteristics were extracted from the model at selected cross-section locations shown in Figure 59, with the results shown in Table 12. Cross-sections was drawn upstream (EX STA 14+75) and downstream (EX STA 12+72) near the roadway crossing to observe the hydraulic impact of SR 3 in the existing conditions. The remaining four cross-sections were drawn at measured BFW locations (EX STA 10+47, 10+65, 15+50, and 16+45). Appendix H contains additional cross-sectional plots, as well as plan and profile view figures of hydraulic model results.

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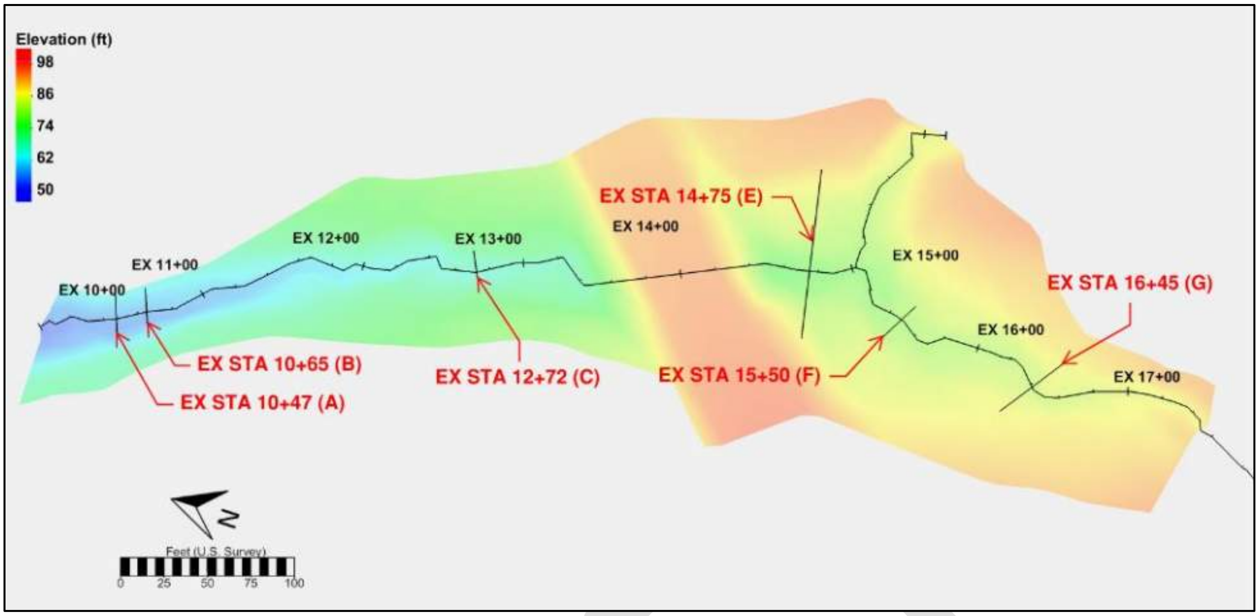

Figure 59. Locations of cross-sections used for results reporting

Table 12 shows results from cross-sections in the upstream and downstream reaches. Hydraulic results in the DS design reach are typical of streams with similar size and flow. Shear stress is relatively low, likely due to the recent incision that has made the channel bottom wider than is typical for similar crossings (Section 2.7.4). At upstream cross-section (E), the water depth is 5.5 feet at the 100-year event. This is due to backwatering caused by the undersized existing 2-foot-diameter culvert. As a result, velocity and shear stress values in this region are very low or zero. Hydraulic results at cross-section (G) are only slightly affected by backwatering and the 100-year flow and cross-section (F) is not affected.

Table 12. Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross-section	2-year	100-year	500-year
Average WSE (ft)	DS 10+47 (A)	55.7	56.4	56.6
	DS 10+65 (B)	56.4	57.1	57.3
	DS 12+72 (C)	66.0	66.8	67.1
	Structure (D)	NA	NA	NA
	US 14+75 (E)	76.1	80.9	86.1
	US 15+50 (F)	79.5	80.9	86.1
	US 16+45 (G)	82.5	83.1	86.1
Max depth (ft)	DS 10+47 (A)	0.9	1.6	1.8
	DS 10+65 (B)	0.7	1.4	1.7
	DS 12+72 (C)	0.7	1.6	1.9
	Structure (D)	NA	NA	NA
	US 14+75 (E)	0.7	5.5	10.7
	US 15+50 (F)	0.7	2.2	7.3
	US 16+45 (G)	0.7	1.3	4.2
Average velocity (ft/s)	DS 10+47 (A)	2.1	3.3	3.7
	DS 10+65 (B)	2.6	4.4	4.9
	DS 12+72 (C)	2.6	3.3	3.3

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Hydraulic parameter	Cross-section	2-year	100-year	500-year
	Structure (D)	NA	NA	NA
	US 14+75 (E)	2.1	0.3	0.1
	US 15+50 (F)	2.5	0.9	0.2
	US 16+45 (G)	2.1	3.5	0.5
Average shear (lb/SF)	DS 10+47 (A)	0.8	1.5	1.8
	DS 10+65 (B)	1.0	2.1	2.5
	DS 12+72 (C)	1.0	1.2	1.2
	Structure (D)	NA	NA	NA
	US 14+75 (E)	0.9	NA	NA
	US 15+50 (F)	1.0	0.2	NA
	US 16+45 (G)	0.8	1.6	0.1

Note: Main channel extents were based off topographic grade breaks.

The 100-year flow produces a backwater condition that extends 132 feet upstream of the inlet to EX STA 15+80. Ponded water also extends up the east tributary channel for approximately 33 feet. Flooding expands to a maximum of approximately 53 feet wide at EX STA 14+48. A profile showing the results of the inundation for the 2-year, 100-year, and 500-year flows is shown in Figure 60.

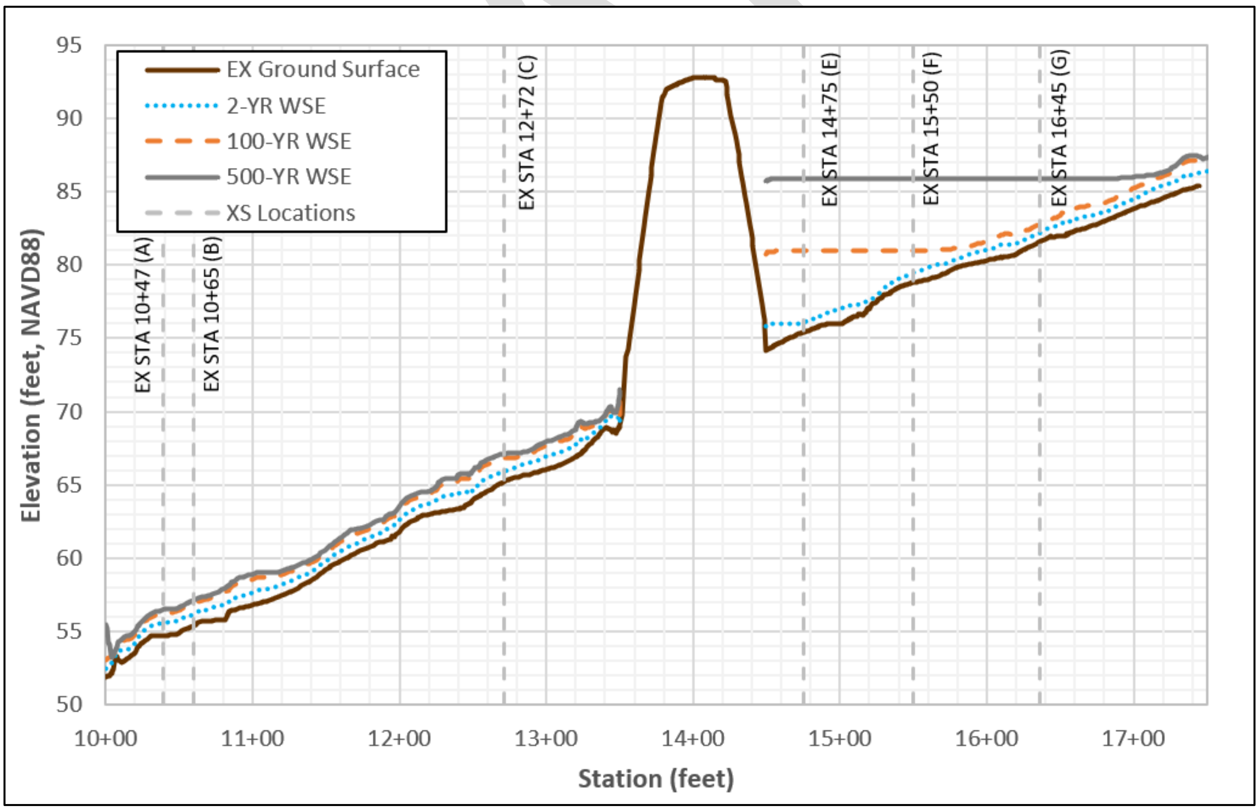

Figure 60. Existing-conditions water surface profiles

Figure 61 shows the WSE of the 2-, 100-, and 500-year flow event at cross-section (A) which is close to the beginning of the DS design reach. DS BFW #3 is located approximately 30 feet upstream of cross-section (A). The channel has incised, causing the 2-year flow to be considerable below the defined right bank.

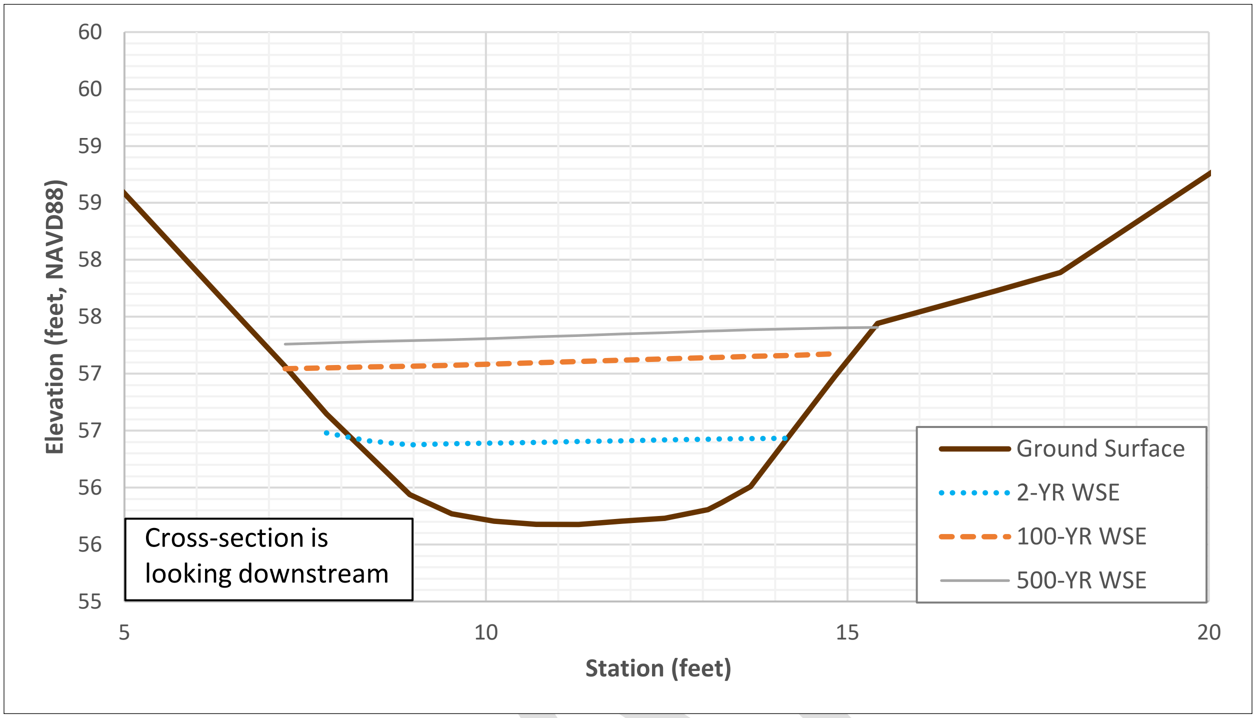

Figure 61. Cross-section near DS BFW #6 STA 10+47 (A) looking downstream

Cross-section (F) was drawn at EX STA 15+50 (US BFW #1) which is approximately where the downstream end of the US design reach begins. The 2-year flow width at this location is 5.2 feet which is 0.2 feet greater than the BFW measured at site visit 2. The measured bankfull depth 0.8 feet which is 0.1 foot lower than the existing condition modeled 2-year flow depth. These results verify that the existing-conditions model has similar flow characteristics at this flow, as would be expected from site data and observations. Note, the 100-yr and 500-yr water surface elevations at this cross-section are within the area of backwatering from the culvert and are thus higher than they would be in free-flowing conditions (see Figure 60).

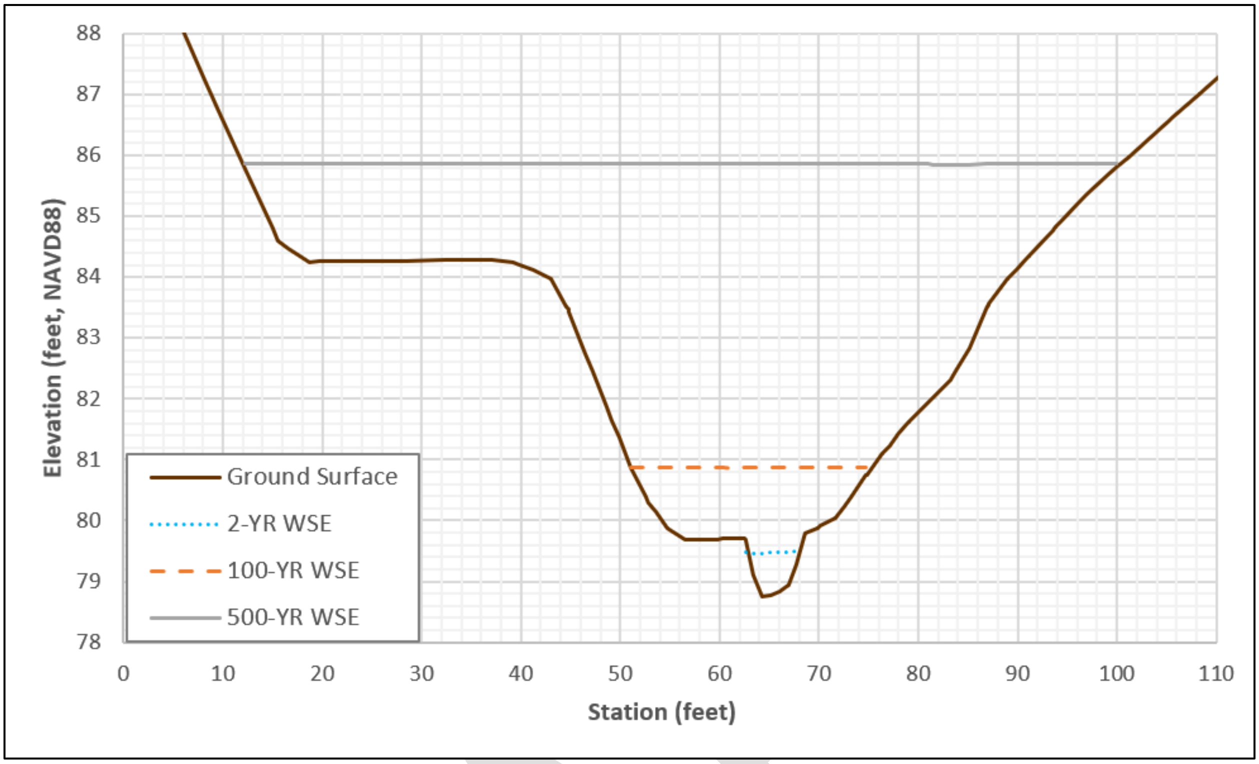

Figure 62. Cross-section at STA 15+50 (F) looking downstream

Velocities of approximately 10 fps are observed at the culvert outlet. This is caused by the steep culvert slope of 5.1 percent, which is the reason the crossing is a fish passage barrier (Section 2.1). This explains the approximately 1-foot-deep scour hole at the culvert outlet (Figure 14). Figure 63 shows the extent of upstream flooding at the 100-year event.

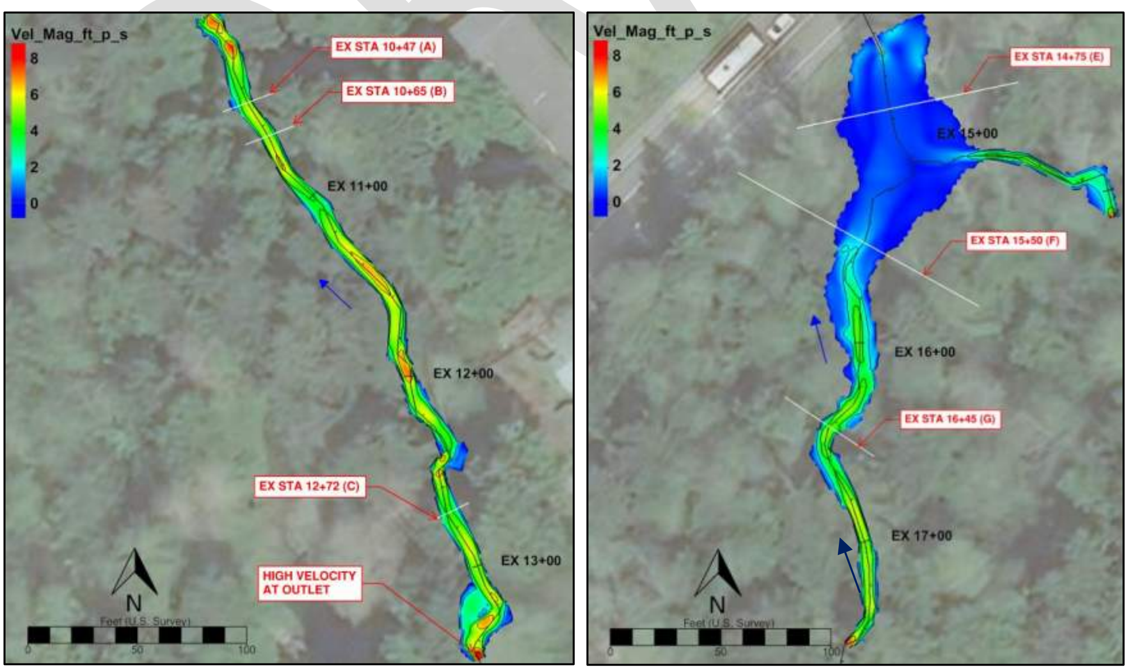

Figure 63. Existing-conditions 100-year velocity map with cross-section locations

Table 13. Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 10+47 (A)	NA	3.3	NA
DS 10+65 (B)	NA	4.3	NA
DS 12+72 (C)	NA	3.3	NA
Structure (D)	NA	NA	NA
US 14+75 (E)	NA	0.3	0.2
US 15+50 (F)	NA	1.1	0.5
US 16+45 (G)	NA	3.7	2.1

Right overbank (ROB)/left overbank (LOB) locations were approximated based off topographic grade breaks.

5.3 Natural Conditions

A natural conditions model was not required as the system is confined.

5.4 Proposed Conditions: 13-Foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The preliminary hydraulic modeling complete for this report assumes the most conservative conveyance and scour possibility of vertical walls at the edge of the minimum hydraulic width. See Section 4.2.2 for a description of how the minimum hydraulic width was determined.

The proposed-conditions SRH-2D model results were used to evaluate the hydraulic conditions within the proposed crossing that has a 13-foot-wide hydraulic width for the 2-, 100-, 2080 100-, and 500-year peak flood events at the project site. Inundation extents and results extracted at selected cross-section locations are discussed in the following paragraphs. Appendix H contains additional cross-sectional plots as well as plan view figures of hydraulic modeling results. The proposed-conditions model results extracted from the selected cross-sections A through G are shown in Table 14. The locations of the cross-sections along the proposed alignment are shown in Figure 64.

Cross-sections in the proposed model are at the same locations as the existing model with the exception of the added mid-crossing section. This provides a direct comparison between the existing and proposed results. Cross-section figures are generated from observation lines in SMS and tabular results are generated from 1-D hydraulics cross-sections.

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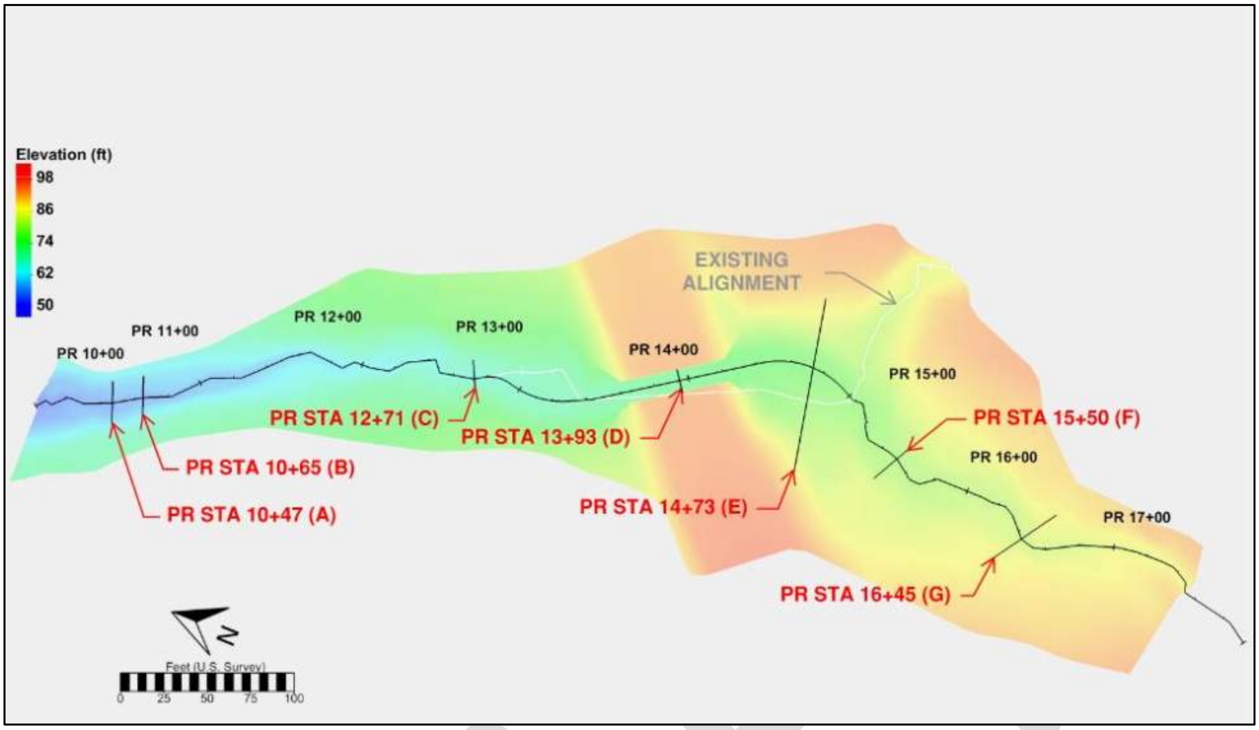

Figure 64. Locations of cross-sections on proposed alignment used for results reporting

The WSE at cross-sections are generally very similar between the existing and proposed scenarios. The only exception is the dramatic reduction in 500-year and 2080 100-year WSE in the proposed scenario due to the lack of backwater from the undersized culvert (Appendix H). Proposed model results show no backwater or constriction of flow by the 13-foot-wide structure.

The 100-year flow does contact the sidewalls of the crossing structure at a maximum depth of 0.5 feet and the climate change 2080 100-year flow reaches a maximum depth of 0.9 feet up the side of the structure wall (Figure 66). The proposed model results indicate a 2-year flow depth and width of approximately 0.8 feet and 10.2 feet, respectively. The flow width is larger than measured BFWs because the 2-year flow slightly overtops the proposed channel banks (Figure 65).

Table 14. **Average main channel hydraulic results for proposed conditions**

Hydraulic parameter	Cross-section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 10+47 (A)	55.7	56.4	56.6	56.6
	DS 10+65 (B)	56.4	57.1	57.4	57.4
	DS 12+71 (C)*	65.9	66.7	67.1	67.0
	Structure 13+93 (D)	71.8	72.4	72.7	72.6
	US 14+73 (E)*	75.5	76.1	76.3	76.3
	US 15+50 (F)	79.5	80.0	80.2	80.2
	US 16+45 (G)	82.5	83.1	83.4	83.3
Max depth (ft)	DS 10+47 (A)	0.9	1.6	1.8	1.8
	DS 10+65 (B)	0.7	1.4	1.7	1.6
	DS 12+71 (C)*	0.7	1.5	1.9	1.8
	Structure 13+93 (D)	0.8	1.4	2.0	2.0
	US 14+73 (E)*	0.8	1.4	1.6	1.6
	US 15+50 (F)	0.7	1.3	1.5	1.4
	US 16+45 (G)	0.7	1.3	1.6	1.5
Average velocity (ft/s)	DS 10+47 (A)	2.1	3.9	4.5	4.4
	DS 10+65 (B)	2.6	4.4	5.0	4.9
	DS 12+71 (C)*	2.9	3.9	4.2	4.2
	Structure 13+93 (D)	2.9	4.7	5.1	5.1
	US 14+73 (E)*	2.9	4.6	5.0	4.9
	US 15+50 (F)	2.5	4.3	4.8	4.7
	US 16+45 (G)	2.1	3.5	4.1	4.0
Average shear (lb/SF)	DS 10+47 (A)	0.8	1.8	2.2	2.1
	DS 10+65 (B)	1.0	2.1	2.5	2.5
	DS 12+71 (C)*	1.4	1.8	1.9	1.8
	Structure 13+93 (D)	1.4	2.6	3.0	2.9
	US 14+73 (E)*	1.5	2.6	2.9	2.9
	US 15+50 (F)	1.0	2.1	2.4	2.4
	US 16+45 (G)	0.8	1.6	2.1	2.0

*Stationing differs from existing cross-sections but locations are the same.
Note: Main channel extents were based off topographic grade breaks.

Complexity features are proposed within the structure with stable boulders keyed into the edge of the structure to prevent entrainment of flow. The bank irregularities created by the proposed complexity features are represented in the meandering alignment of the proposed surface through the crossing (Figure 50). Increased Manning's roughness in the overbank areas accounts for complexity feature roughness. Velocities at the 100-year flow range from 3.5 fps to 4.7 fps which is reasonable for a channel this size and the type of stream. During final design, the hydraulics of habitat features will be analyzed more closely.

Figure 65 shows the proposed WSE steadily follows the proposed grading and maintains a 100-year flow depth ranging from one to two feet. The 2-year flow width within the crossing is 5.8 feet, which is slightly higher than BFW 1# which is within the upstream design reach (Figure 66).

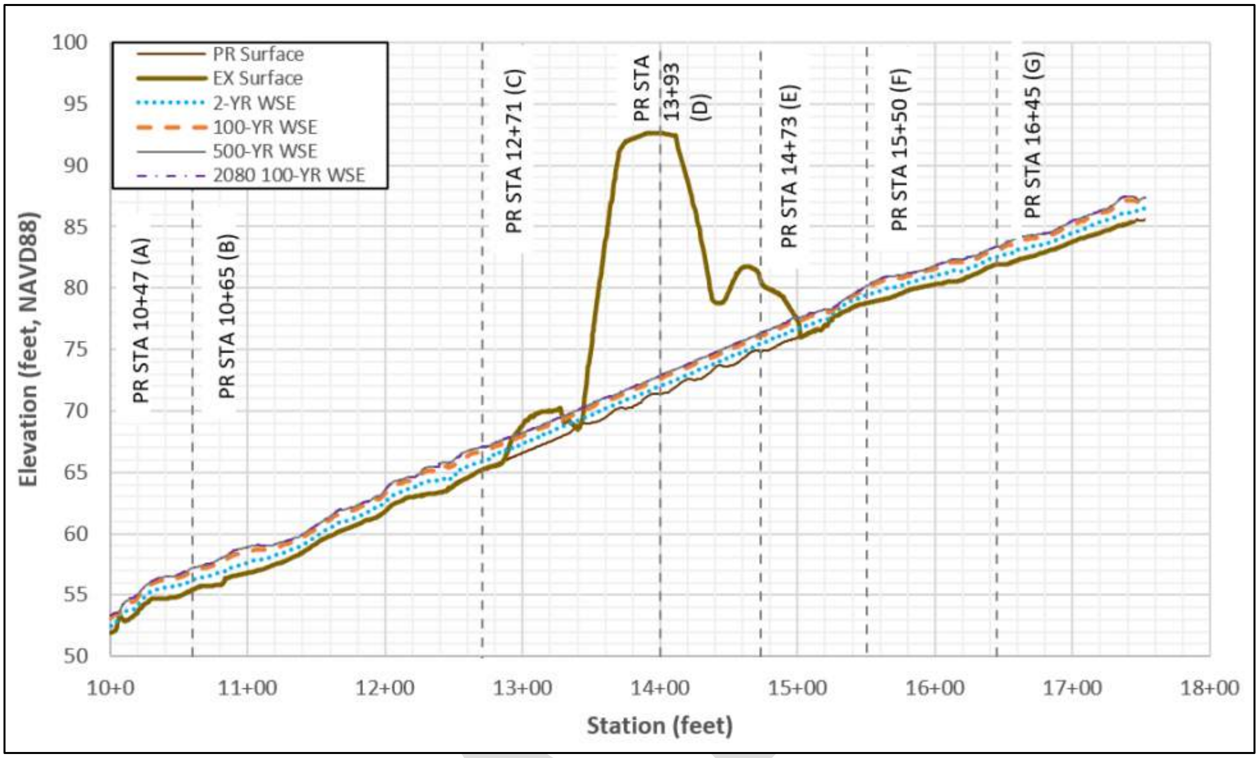

Figure 65. Proposed-conditions water surface profiles

As illustrated in Figure 65, the 2-year flow is close to the top of the main channel bank, while the 100-year flow overtops the proposed overbanks by several inches. Because the meandering bankfull channel is built into the mesh within the crossing, that depth is only shown on the left bend. The 100-year velocity within the structure is within 0.4 fps of the velocity in the upstream design reach.

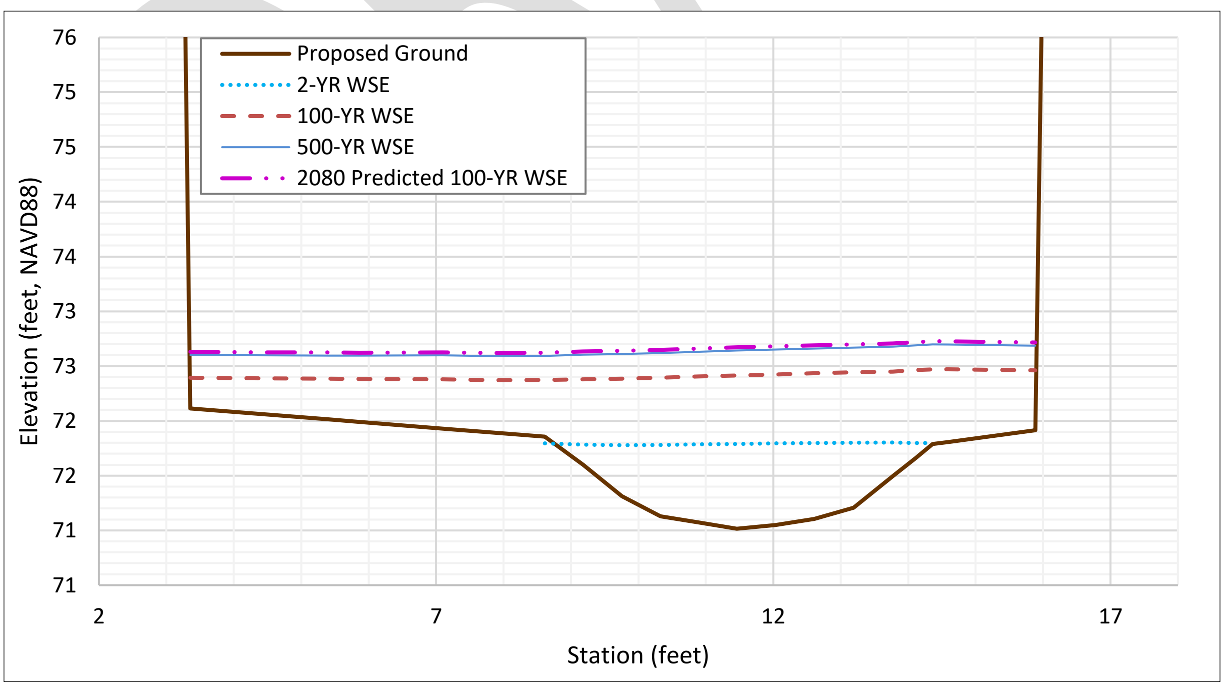

Figure 66. Typical section through proposed structure (STA 13+93)

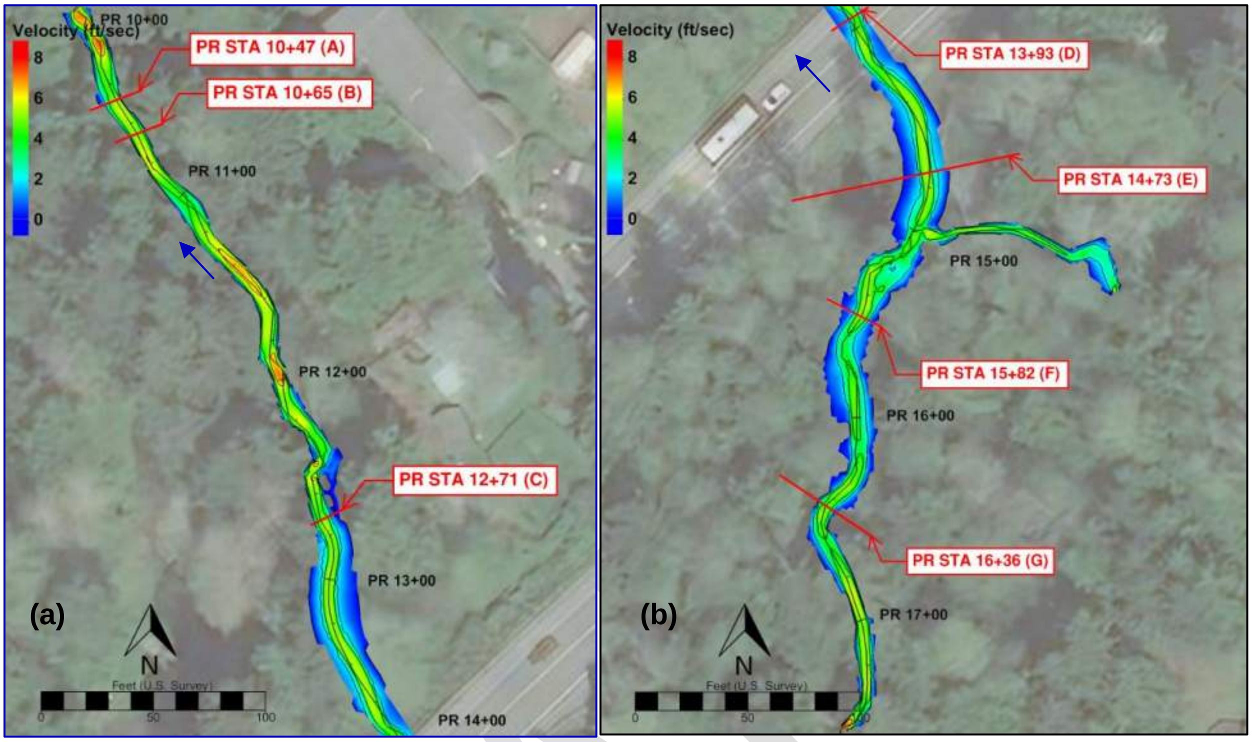

Figure 67. Proposed-conditions 100-year velocity map, upstream (a) downstream (b)

Table 15. Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 10+47 (A)	0.3	3.9	NA	0.4	4.5	NA
DS 10+65 (B)	NA	4.4	NA	NA	5.0	NA
DS 12+71 (C) *	NA	4.0	0.4	NA	4.2	0.9
Structure 13+93 (D)	2.0	4.7	2.0	2.7	5.1	2.5
US 14+73 (E)*	0.8	4.6	1.7	0.9	5.0	1.7
US 15+50 (F)	1.1	4.3	0.7	1.5	4.8	0.9
US 16+45 (G)	NA	3.5	1.3	NA	4.1	1.9

*Stationing differs from existing cross-sections but locations are the same.
Note: Main channel extents were based off topographic grade breaks.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA) (See Appendix A for FIRMette). The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

In the existing-conditions iteration, the existing 2-foot culvert causes backwatering at the 100-year flow event for about 140 feet upstream of the project culvert (Figure 68). Upstream from there the existing and proposed WSEs closely match. With the proposed crossing in place the model shows a drop of about 6.4 feet in WSE immediately upstream of the crossing. The two WSEs converge within 20 feet of the downstream regrade extent and remain virtually identical in the remainder of the downstream reach.

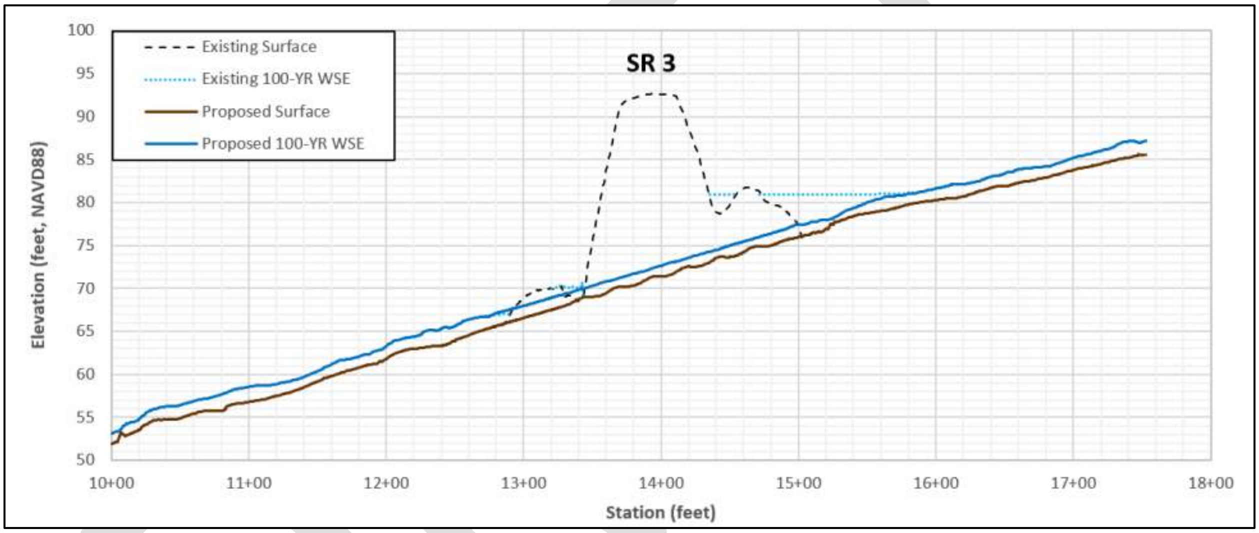

Figure 68. Existing and proposed conditions 100-year water surface profile comparison along proposed alignment

The change in WSE between existing and proposed conditions at the 100-year flood event is shown in Figure 69. Negative numbers (represented by shades of blue colors) show where the future conditions water depth is lower than the existing condition water depths, while positive numbers (represented by yellow to red colors) indicate the opposite. The dark blue fill in Figure 69 shows newly dried area around the culvert inlet as the proposed crossing reduces the inundation caused by the backwater condition. The red fill in Figure 69 shows the newly inundated area created by the proposed regrading. There is no infrastructure within the limit of newly inundated area. No risk is posed to properties or infrastructure in the proposed conditions. A flood risk assessment will be developed during later stages of the design.

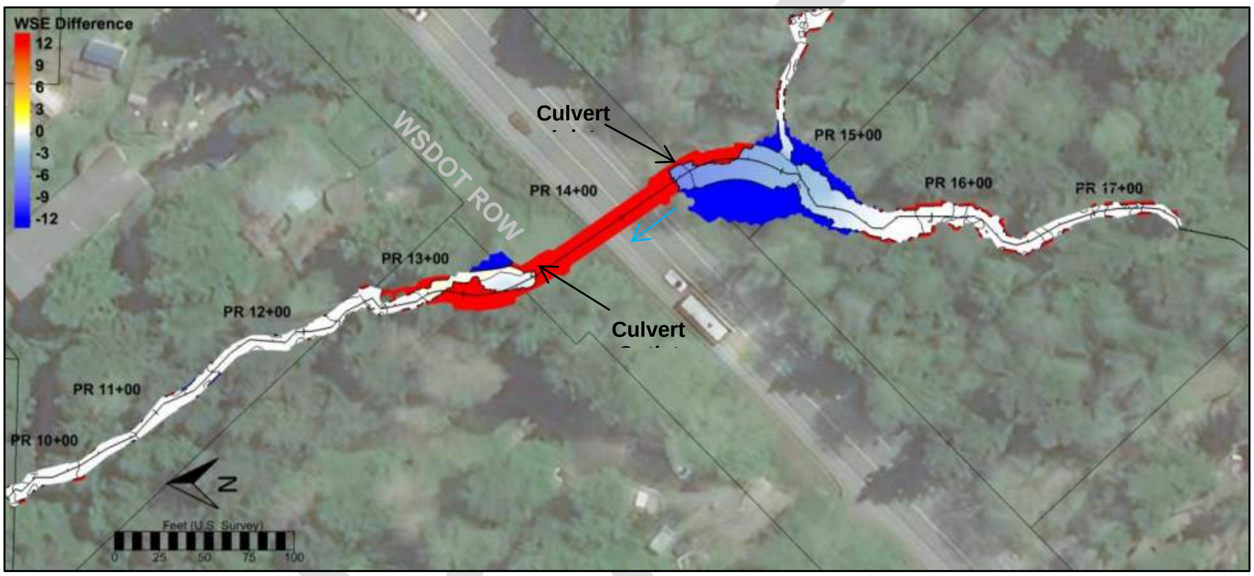

Figure 69. 100-year WSE change from existing to proposed conditions

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation, and evaluation of preliminary total scour are based on available data, including but not limited to LiDAR profile, survey thalweg elevation, and geotechnical boring data. This evaluation is to be considered preliminary and is not to be taken as a final recommendation.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended MHO, and considering the potential for lateral channel migration, preliminary calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson, Zevenbergen, Lagasse, & Clopper, 2012). For this crossing both the design and the check flood were determined to be the 2080 projected 100-year event (55.6 cfs). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The preliminary geotechnical report boring data shows the first approximately 17 feet of soil over SR 3 is made of a roadway fill and cohesionless, coarse-grained very loose, silty sand from glacial deposits (WSDOT Geotechnical Office, 2022). At the upstream end of the proposed channel, 17 feet below the road surface, the geotechnical memo shows loose silty sand. This transitions into a more consolidated sandy silt described as "hard, gray, moist, homogeneous, blocky" at the downstream end of the structure, 20 feet below the road surface. No large-scale channel migration of the UNT to Hood Canal is observed in the LiDAR data (Figure 41) (DNR, 2018). There were a couple of small, isolated patches of erosion-resistant glacial till noted in the downstream reach, but their extent is unknown. The recent incision observed downstream of the project crossing supports geotechnical results indicating portions of the channel have erodible soil properties (Figure 18). However, the relatively steep slope and confined nature of the stream through the crossing makes large-scale lateral migration unlikely. Upstream of the crossing the reach is relatively flat; however, there was no evidence of lateral migration or erosion. The UNT to Hood Canal is not expected to move significantly laterally but has potential to adjust horizontally due to external forcings such as LWM within the confines of the creek's ravine as described in Section 2.7.5.

Lateral migration is not dependent on the structure type selected. The sinuosity of the main channel is primarily caused by naturally forcing LWM and boulder features in the system (Figure 10). This dynamic physical process of stream sinuosity and channel meandering capabilities is considered in the proposed LWM design. The model results of velocities and shear stress within the proposed crossing are relatively low (Table 14). Localized scour around proposed habitat features is expected. The modeled 100-year WSE will interact with the structure wall of the proposed 13-foot MHO width, and scour analysis assume the stream could migrate to the edge of the proposed structure. This will be reevaluated in later stages of design.

7.2 Long-Term Degradation of the Channel Bed

Long-term degradation at the project crossing was estimated based on site visit observations, watershed assessment, LiDAR profile (DNR, 2018), survey topography, and geotechnical data. Results from the WSDOT geotechnical scoping memorandum show a somewhat erosion-resistant glacial deposit layer of hard sandy silt with scattered angular gravel at approximately elevation 53 feet (precise elevations were not available as the boring location had not been surveyed) (WSDOT Geotechnical Office, 2022). While this layer would likely limit erosion, it is below the elevation to which scour is expected to reach. Evidence of recent degradation was observed, although no active headcutting was observed in the existing conditions. The channel gradient generally ranges between 1.3 and 5.2 percent aside from a small section of 13.1 percent slope (Figure 41). Potential degradation was quantified by estimating an equilibrium slope, applying this slope to the proposed stream profile starting at a potential knick point at the end of the surveyed channel, and graphically measuring the amount of degradation.

The average long-term gradient through the SR 3 crossing is estimated to be 3.8 percent by projecting the slope of the downstream reach. The straight, regraded channel slope is steeper at 4.7 percent. The base level control occurs downstream at a hydraulic controlling LWM step (Figure 26). Projecting the 3.8 percent slope from the downstream base level control point results in an estimated degredation upstream of 4.0 feet (Figure 70). The upstream catch point of the slope is unknown and does not impact degradation depth at the crossing. The Kitsap County LiDAR profile runs along the existing alignment. The WSDOT topographic survey travels along the proposed alignment. The long-term degradation estimate is a conservative estimate based on the potential knickpoint migrating at least 530 feet upstream through the crossing structure. The terminus of the potential head cut is not known, but it is assumed to be upstream of the proposed crossing.

The preliminary geotechnical report boring data shows the first approximately 17 feet of soil is made of a roadway fill and cohesionless, coarse-grained very loose, silty sand from glacial deposits (WSDOT Geotechnical Office, 2022). The next 18- to 43-foot segment of soil (approximately elevation 53 feet to 27 feet) consists of cohesive, fine-grained, hard, sandy silt and stiff clay. The upper portion of this unit is estimated to be an erosion-resistant glacial till layer that would limit erosion, although based on the preliminary data it is below the potential long-term degradation depth.

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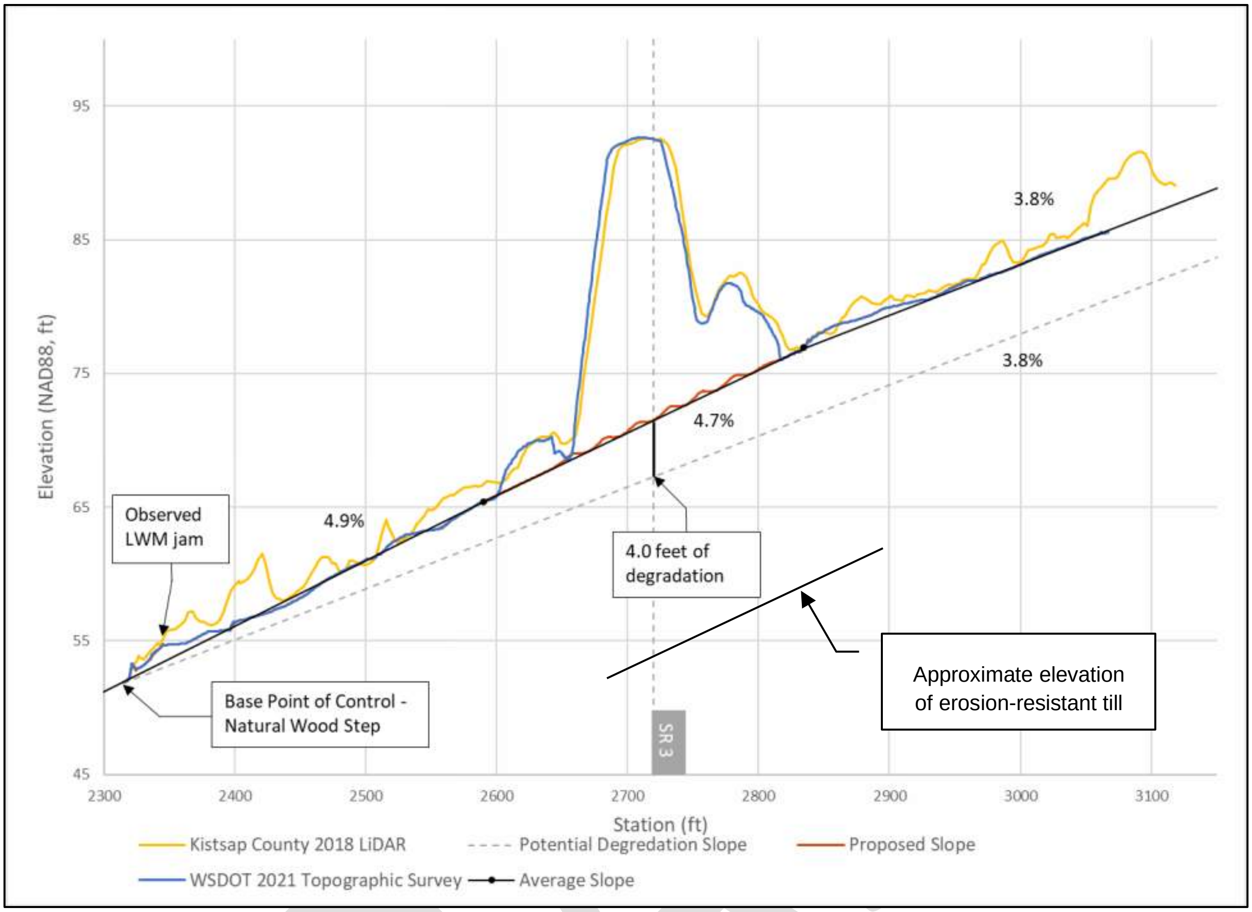

Figure 70. Potential long-term degradation at the proposed structure

7.3 Contraction Scour

The contraction scour for the project crossing was estimated following the methodology outlined in Chapter 6 of HEC-18 (Arneson, Zevenbergen, Lagasse, & Clopper, 2012). This estimation used the Bridge Scour Analysis tool in Hydraulic Toolbox for calculation (FHWA, 2022). Contraction scour can be classified as live-bed or clear-water scour. The critical velocity of the proposed D_{50} was calculated and compared to the average velocity upstream of the structure to determine the scour condition of the crossing.

Potential contraction scour in the crossing was examined using the contraction scour analysis in Hydraulic Toolbox. The 2-, 5-, 10-, 25-, 50-, 100-, 500-, and projected 2080 100-year proposed model results from Section 5.4 were used for the analysis. Flow between the top-of-banks was used to calculate the unit flow values, assuming the majority of sediment transport will occur through the 5.8-foot-wide main channel. The results indicate that the proposed crossing will be under clear-water conditions up to and including the 2080 projected 100-year flow, the event with the largest flow at this crossing. The results show no contraction scour in the main channel during the 2080 100-year event. See Appendix K for detailed contraction scour calculations.

7.4 Local Scour

The following sections described the scour methodology and results of the local scour components.

7.4.1 Pier Scour

The crossing will not have piers and, therefore, pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. Assuming the most conservative scenario when abutments are constructed immediately on two sides of the 13-foot-wide MHO, the 2080 100-year flow will fill the channel and engage the abutment structure to a depth of 0.8 feet on the floodplain benches (Figure 66). Calculations were done using the Abutment Scour tool in Hydraulic Toolbox. The type of abutment scour in the proposed crossing was clear-water during all the simulated events. The 2080 100-year flow is the scour design flood and the scour check flood since it produced the deepest scour depth among all the simulated events (Appendix K). Scour at the thalweg was calculated to be 0.3 feet for both (FHWA, 2022). This assessment is specific to the 13-foot MHO that is currently proposed by PACE. It should be reevaluated when a structure type is recommended for this crossing by WSDOT in later stages of the design (Section 4.2.6).

7.4.3 Bend Scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed UNT to Hood Canal SR 3 crossing as shown in the plans dated July 28, 2022, are provided in Table 16. The total scour of the project crossing is evaluated up to 2080 100-year flow, which is estimated to exceed the 500-year peak flow by approximately 2 cfs. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 16. These preliminary recommendations could change as the design progresses and should be reevaluated during later stages of design.

Table 16. Scour analysis summary

Calculated Scour Components and Total Scour for SR 3 UNT to Hood Canal		
	Scour design flood (2080 100-year predicted flow)	**Scour check flood (2080 100-year predicted flow)**
Long-term degradation (ft)	4.0	4.0
Contraction scour (ft)	0.0	0.0
Local scour (ft)[a]	0.3	0.3
Total depth of scour (ft)[b]	**4.3**	**4.3**

[a] Local scour was estimated using Abutment Scour tool in Hydraulic Toolbox with method outlined in NCHRP 24-20, which includes contraction scour.

[b] Total scour includes long-term degradation plus contraction or local scour, whichever is greater. Depth of total scour should be applied to the thalweg elevation of the proposed channel to determine the total scour elevation at each infrastructure component (e.g., structure, walls, roadway embankments, scour countermeasure, etc.).

8 Scour Countermeasures

The estimated total scour depth during both the scour design flood and the scour check flood is 4.3 feet for the proposed 13-foot MHO structure. Assuming all structure foundations, including any abutment wall, wing walls, and retaining walls, extend below the scour design and check flood total depth of scour then scour countermeasures are not necessary for the project crossing. If non-structure wall foundations do not extend below the elevation associated with the total depth of scour, then the need for scour countermeasures will be reevaluated in a later stage of design once walls and their corresponding foundation designs are determined.

The likelihood of scour countermeasures increases if LWM is placed within the structure footprint. Elements of a water crossing that may need a scour countermeasure include but are not limited to walls and the roadway embankment. Structural foundations cannot rely on scour countermeasure for the integrity of the structure. If scour countermeasures are deemed necessary, they will not encroach within the minimum hydraulic width unless there has been additional coordination and acceptance from WDFW and Tribes.

The potential scour extents are based the conceptual structure and wingwall locations and shown in the proposed channel profile in Appendix D. At this level of design the potential scour extents are contained within WSDOT ROW and would not require special easement acquisition.

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9 Summary

Table 17 presents a summary of the results of this PHD Report.

Table 17. Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	6,014 LF	2.1 Site Description
Bankfull width	Reference reach found?	Upstream and Downstream Design Reach	2.7.1 Reference Reach Selection
	Average Upstream BFW	5.8 ft	2.7.2 Channel Geometry
	Average Design BFW	7.4 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	13.1	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	US 2.3 DS 1.4	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	38.6 cfs	3 Hydrology and Peak
	2080 100 yr flow	55.6 cfs	3 Hydrology and Peak
	2080 100 yr used for design	Y	3 Hydrology and Peak
	Dry channel in summer	No	3 Hydrology and Peak
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform
Channel slope/gradient	Existing culvert	5.1%	2.6.2 Existing Conditions
	Upstream Design Reach	3.4%	
	Downstream Design Reach	4.6%	2.7.1 Reference Reach Selection
	Proposed Straight	4.7%	4.1.3 Channel Gradient
	Proposed Sinuous	4.6%	4.1.3 Channel Gradient
Hydraulic width	Existing	2 ft diam. conc. culvert	2.6.2 Existing Conditions
	Proposed	13 ft	4.2.2 Hydraulic Width
	Added for climate resilience	Yes	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	1 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100-year	4.2.3 Vertical Clearance
	Maintenance clearance	Required 10 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	99.2 ft	2.6.2 Existing Conditions
	Proposed	60.4 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	NA	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	No	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity

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Stream crossing category	Element	Value	Report location
	LWM within structure	Yes (small wood)	4.3.2 Channel Complexity
	Boulder clusters	Yes	4.3.2 Channel Complexity
	Individual Boulders	Yes	4.3.2 Channel Complexity
	Coarse bands	No	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	Yes	2.7.5 Channel Migration
	Floodplain changes?	NA	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	Approximately 4.0 ft	7.2 Long-Term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-Term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning’s Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment

Appendix K: Scour Calculations

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Scour Countermeasure Calculations (FHD ONLY)

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Appendix A: FEMA Floodplain Map

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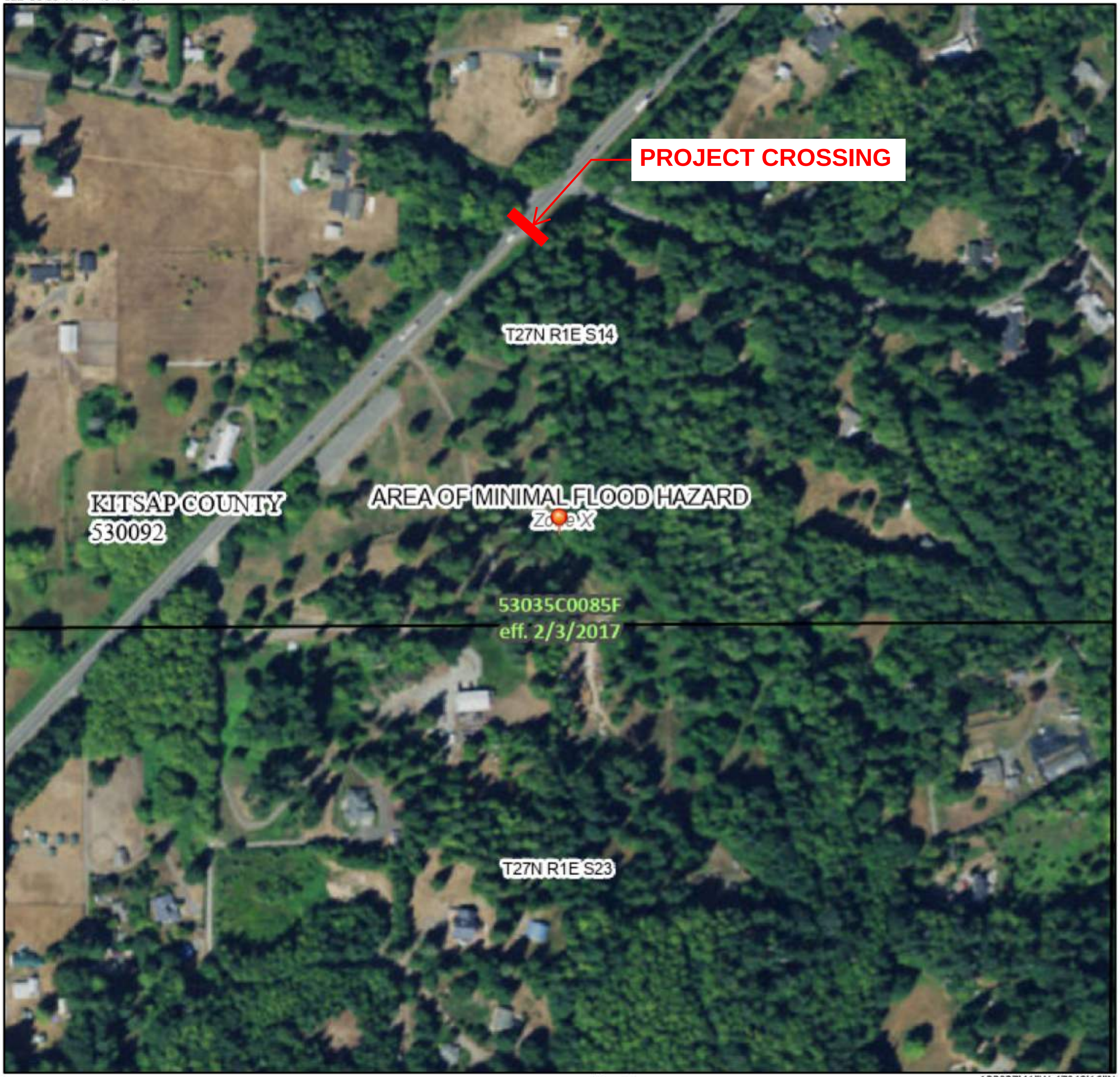
National Flood Hazard Layer FIRMette

FEMA

122°38'18"W 47°49'40"N



122°37'41"W 47°49'16"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS		Without Base Flood Elevation (BFE) *Zone A, V, A99*
		With BFE or Depth *Zone AE, AO, AH, VE, AR*
		Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD		0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
		Future Conditions 1% Annual Chance Flood Hazard *Zone X*
		Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
		Area with Flood Risk due to Levee *Zone D*
OTHER AREAS	NO SCREEN	Area of Minimal Flood Hazard *Zone X*
		Effective LOMRs
		Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES		Channel, Culvert, or Storm Sewer
		Levee, Dike, or Floodwall
OTHER FEATURES	B 20.2	Cross Sections with 1% Annual Chance
	17.5	Water Surface Elevation
	8	Coastal Transect
	513	Base Flood Elevation Line (BFE)
		Limit of Study
		Jurisdiction Boundary
		Coastal Transect Baseline
		Profile Baseline
		Hydrographic Feature
MAP PANELS		Digital Data Available
		No Digital Data Available
		Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 6/20/2022 at 7:55 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

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Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554 Task AC
	Project Name: SR003 MP58-21 Unnamed to Hood Canal 991240	Date: 2021.12.02
	Project Office:	Time of Arrival: 12:10 pm
	Stream Name: Unnamed	Time of Departure: 2:20 pm
WDFW ID Number: 991240	Tributary to: Hood Canal	Weather: Overcast with occasional rain, ~45° F
State Route/MP: SR003 MP58-21	Township/Range/Section/ ¼ Section: T27N R1E S14	Prepared By: H. Moen, T. Wang
County: Kitsap	Purpose of Site Visit: Identify reference reach and collect BFW measurements	WRIA: 15.0367A

Meeting Location:
Walmart at 21200 Olhava Way NW, Poulsbo, WA 98370 parking lot

Attendance List:

Name	Organization	Role
Shane Sheldon	PACE	Lead Engineer
Colin Nicol	PACE	Environmental Scientist
Tasha Wang	PACE	Project Engineer
Henry Moen	PACE	E.I.T.

Hood Canal Unnamed Tributary – State Route (SR) 3 Crossing Site ID: 991240 (Crossing 991240) has been identified as a fish passage barrier by Washington Department of Fish and Wildlife (WDFW). PACE is working with WSDOT to complete a preliminary design for a fish-passable crossing. The following Hydraulics Field Report documents the geomorphic, biological, and hydraulic field assessment of Crossing 991240 conducted by PACE. The relevant reaches both upstream and downstream of the crossing, can be accessed directly from SR 3 by parking approximately 300 ft southwest of the crossing, in a nearby residential road, NE Sunset Way.

General Site Description

Crossing 991240 is located along SR 3 milepost (MP) 58.21 in Kitsap County, Washington. This crossing carries run-off from the Port Gamble Heritage Forest through an unnamed tributary to the Hood Canal. The WDFW Level A Culvert Assessment report, conducted in January 2010, states that the crossing is a 2-foot-diameter round plain cement concrete (PCC) culvert with a length of 27.40 m (90.0 ft) and a slope of 4%. The inlet opening is at the toe of the road fill, with steep banks approximately 50% slope on two sides (Photo 1). The outlet drops into an approximately 1-foot-deep and 15-foot-long plunge pool (Photo 2). At the site visit the slope of the crossing was not verified; however, the culvert size was measured to be 2 feet.

Bankfull Width:

A total of six bankfull widths (BFW) were taken during the site visit, three downstream of the crossing and three upstream of the crossing located in the reference reach (Table 1). Important channel geometry features at each BFW location were sketched in Photo 3, including BFW, bankfull depth (BFD), bottom width, and vegetation and moss covers that help identify BFW.

Upstream Reach

The upstream BFW measurements were taken approximately 100 feet to 180 feet upstream of the crossing within the reference reach. The channel in this area has a main low flow channel within vertical banks approximately 0.8 foot high and benches on two sides.

The first BFW measurement (U/S BFW #1) was taken at about 100 feet upstream of the crossing. The low flow channel meander within the floodplain in this section of the reach (Photo 5). U/S BFW #1 was taken at a riffle bend from top of bank to top of bank (Photo 3 (a)). The second BFW measurement (U/S BFW #2), located 130 feet upstream of the crossing, was taken where the stream widens out to a shallow bench (Photo 6). The left overbank (LOB) is wet and muddy, and the field crew decided to include this bench in the BFW measurement, yielding a larger BFW than other measurements. An 8-inch log lies along the toe of the right bank. U/S BFW #2 was taken at the bank top above the toe log and projected to the other side of the bank (Photo 3 (a)). The third BFW measurement (U/S BFW #3) was taken at approximately 180 feet upstream of the crossing and the end of the reference reach. The right bank is less vertical at this location and has a secondary bench (Photo 3 (a)). U/S BFW #3 was taken at the edge of vegetation marked by moss and fern, above the secondary bench (Photo 7).

<u>Downstream Reach</u>

The downstream reach has a very defined main channel with undercut banks ranging from 1.6 to 2.4 feet high. The first downstream BFW measurement (D/S BFW #1) was taken approximately 170 feet downstream of the crossing close to a footpath that was used by the property owners to access this reach. The channel has a 6.6-foot-wide bottom and the banks rise 1.6 feet high to reach benches on both sides (Photo 3 (a) and Photo 8 (a)). D/S BFW #1 was measured where the vegetation growth starts at the top of banks. The second downstream BFW (D/S BFW #2) was taken approximately 240 feet downstream of the crossing. A 48-inch down tree across the channel is located between the D/S BFW #1 and D/S BFW #2 locations. There was a bench present on the left bank and a 2.4-foot vertical bank on the right bank. D/S BFW #2 was taken 1.1 feet above the thalweg at the level of erosion and moss growth. A 1-foot boulder was observed within this cross-section. The third downstream measurement (D/S BFW #3) was taken approximately 320 feet downstream of the crossing. This section of the reach is located within a wider valley. There is a low bench on the left side of the channel abutting a steep bank to the top of the valley (Photo 3 (a)). The vertical right bank leads to an undercut terrace that is 1.6 feet high (Photo 9). D/S BFW #3 was measured from the top of left bench to the top of right bank. Another 100 feet downstream of D/S BFW #3, there is a property boundary fence that crosses the stream.

Table 1: Bankfull Width Measurements

	Approximate Distance from Crossing (ft)	Bankfull Width (ft)	Source/Date
U/S BFW #1	100 (upstream)	5.0	PACE (December 2021)
U/S BFW #2	130 (upstream)	17.2	PACE (December 2021)
U/S BFW #3	180 (upstream)	9.0	PACE (December 2021)
D/S BFW #1	~170 (downstream)	8.3	PACE (December 2021)
D/S BFW #2	~240 (downstream)	7.3	PACE (December 2021)
D/S BFW #3	~320 (downstream)	6.7	PACE (December 2021)
	Design Average	**8.9**	

Reference Reach:

The reference reach is located between 100 feet and 180 feet upstream of the crossing where no influence from the existing crossing is shown. The channel has a defined main channel and a floodplain 10 to 20 feet wide. This section of the channel covers a variety of channel geometry. The main channel 100 feet upstream of the crossing is approximately 5 feet wide with vertical banks connecting to the floodplain. More signs of floodplain inundation were observed farther upstream, such as muddy floodplain, lower main channel banks, and wider main channel up to 9 feet. This section of the upstream reach has little signs of incision and abundant LWM to provide habitat benefits. There was no obvious sign of impact from human activities.

Approximately 40 feet upstream of the crossing inlet a tributary joins Unnamed to Hood Canal. We call this tributary East Trib in the rest of this report. The drainage area of East Trib is smaller than the drainage area of Unnamed to Hood Canal and at the time of the site visit the majority of flow appeared to be in the main channel. The additional drainage area that flows through the crossing, but does not flow through the reference reach, will need to be considered during the design phase.

To account for the flow from the upstream two tributaries, the BFW measurements from both the upstream and the downstream reach are included in the design average BFW. Note the BFW measurements downstream of the crossing were not significantly different from upstream. There are clear signs of recent channel incision in the downstream reach such as vertical banks with exposed roots and sharp angles at the break in slope at the top of bank (Photo 17) . The downstream reach is located within private property and the design team consulted the property manager during the site visit about the recent history of the channel. He reported that recent high flows had resulted in noticeable downcutting in the channel. He also mentioned that he and other property owners cleared the stream of large woody material (LWM) to prevent flooding. Although the BFW will be used for design, the active incision in the downstream reach indicates it is not a suitable reference reach.

Data Collection:

The entire attendance list participated in the collection of data. Data was collected both upstream, from the inlet until roughly 180 feet from the inlet, and downstream from the outlet until about 300 feet from the outlet. Data collected included:

- General Site observations
- Bankfull width measurements
- Other channel measurements (Bank height, channel width, water depth, etc.)
- Pebble counts

Observations:

Geomorphology

Upstream Conditions

The crossing inlet is covered by dense brush and is partially filled with organic debris and sediment (Photo 1). Upstream of the crossing, the stream channel is approximately 5 to 10 feet wide and there is a floodplain bench approximately 1 to 2 feet above the stream channel for the majority of the surveyed reach. The wetted width on the day of the site visit was approximately 5 feet, although it appeared recent higher flows had been much wider and spilled out onto the floodplain in areas. Surrounding the inlet and extending from the top of the roadway prism to approximately 50 feet upstream of the inlet is a dense thicket of vegetation that crowds around the channel (Photo 10). The East Trib joins the main channel in this thicket of vegetation. The slope in this section of the river is low and main channel banks gently slope upward and transition into the surrounding floodplain.

For the next ~80 feet (from ~50 ft to ~130 ft from the inlet) the slope steepens and the stream is dominated by forced pool-riffle morphology. In this section there is forced sinuosity as the stream flows around several rootwads and LWM (Photo 11 and Photo 12), and the banks are steeper and more defined (Photo 13). At ~130 feet from the inlet there is a floodplain that extends to the west approximately 20 feet from the channel. At higher flows it is likely that the stream is well connected with this floodplain. Opposing this floodplain is a toe log following the bank (Photo 14) acting as a steep bank. The following section of river returns to riffle morphology, with established banks and benches on the sides (Photo 7).

Downstream Conditions

The downstream reach is characterized by a well-defined ravine with steep slopes descending to steep, undercut, unstable banks along most of the channel. There is a narrow floodplain bench 2 to 3 feet above the channel along most of the reach. The channel is contained within a 10- to 30-foot valley bottom. Immediately downstream of the crossing is a culvert-induced scour pool which is approximately 1 foot deep and 8 feet long. The banks are heavily lined with blackberry and there are no signs of active degradation in this area. Beginning downstream of the outlet pool, however, the banks become vertical with exposed roots showing and a sharp angle at the top of bank break in slope (Photo 15). The stream makes a couple of sharp bends in this reach. These types of bends are usually forced by LWM or boulders, but no obvious forcing features could be seen. It appeared that the channel had recently incised down and was actively widening and eroding the banks.

Approximately 100 feet downstream the channel widens slightly and the vegetation on the bank transitions from blackberry to salmonberry and dogwood (Photo 16). The channel substrate in this area is gravels and cobbles, with occasional boulders (Photo 16 and Photo 17). The channel in this reach also appears to have recently undergone 0.5 to 2 feet of incision. Approximately 250 feet downstream the channel width is approximately the same and there is a 1- to 2-foot right bank which is either vertical or undercut (Photo 18). The rounded break in slope forming the top of bank indicates any incision here is older than the incision upstream. Cut pieces of wood were observed in the channel, which confirms the property manager account of cutting wood in the channel (Photo 19). Approximately 350 feet downstream of the crossing (near the property boundary) a large down tree was observed in the channel, with other small pieces of wood racking near the larger log (Photo 20). The presence of wood created a more complex thalweg and a 6-inch-deep pool was observed under the wood. The sediment in this area was a mix of sands, gravels, cobbles, and boulders (Photo 21 and Photo 22).

Aquatic Habitat Type and Location

<u>Upstream Conditions</u>

In the WDFW Level I Barrier Assessment the potential species identified for this tributary are coho, steelhead, sea run cutthroat, and resident trout. The flow in the upstream reach was approximately 1 to 6 inches deep in most places, with the stream bed consisting mainly of gravel to cobbles (Photo 13). It is possible there could be some successful spawning activity, especially for smaller resident trout. There were several wood-forced scour pools with vegetation overhanging that could serve as protection from predators (Photo 12). These pools would serve as juvenile rearing habitat, likely for both oversummer and overwinter rearing. During large flood events it is likely there is good connection between the channel and the floodplain, which would offer additional slow velocity refuge habitat. At the first BFW measurement and pebble count there were caddis fly larva present on a significant portion of the substrate above 1 inch in diameter.

<u>Downstream Conditions</u>

Downstream of the crossing the main channel has substrate similar to the upstream, with the streambed consisting mostly of gravel to cobbles, allowing for the possibility of spawning activity. Boulders were seen in the downstream reach and not in the upstream reach, and these boulders created small scour pools as water was forced around them (Photo 22). These small pools could be used for juveniles or residents for rearing habitat. The majority of the reach was a shallow riffle with little complexity, and there were few pools that offered velocity refuge. The banks were undercut and there was vegetation overhanging the channel and lining the banks which would provide protection from predation as well as the possibility for increased foraging of terrestrial invertebrates (Photo 16).

LWM Location and Quantity

<u>Upstream Conditions</u>

In the upstream reach there are a number of key pieces of LWM. Approximately 100 feet upstream of the inlet there is a rootwad (Photo 10) of about 4 feet in diameter, that looked like it had split in two, forcing the stream and restricting the channel width to ~3 feet. Another 20 feet upstream of that rootwad another rootwad (Photo 11) about 3 feet in diameter, forces the stream and acts as a steep bank. At ~130 feet upstream of the inlet a toe log runs along the bank for 30 feet. At ~180 feet, at the upstream end of the reference reach, there is a decomposing log that spans the channel.

<u>Downstream Conditions</u>

On the day of the site visit the survey crew spoke with the downstream property manager who said he cleared wood from the channel to prevent flooding. The field crew observed no LWM in the first 250 feet downstream of the culvert. This area has likely been cleared of wood, leading to observed channel incision. Approximately 350 feet downstream of the crossing there is a large down log spanning the channel, with several smaller pieces of wood racking near the large log (Photo 20).

Vegetation

<u>Upstream Conditions</u>

In the upstream reach the vegetation surrounding the stream is typical of the peninsula with Western red cedar (*Thuja plicata*), Douglas fir (*Pseudotsuga menziesii*), large leaf maple (*Acer macrophyllum*), and red alder (Alnus Rubra) making up the majority of the trees, and sword fern (*Polystichum munitum*), spreading wood fern (*Dryopteris expansa*) and salmonberry (*Rubus spectabilis*) being the predominant groundcover, covering up to and overhanging the stream channel. Of note is that surrounding the inlet is a dense thicket of salmonberries extending from about 30 feet upstream to about halfway up the road prism and up the side of the valley around 100 feet.

Downstream Conditions

The downstream reach is mainly populated by sword fern, salmonberry, western red cedar and Douglas fir. Approximately 200 feet downstream, just past the first BFW measurement, a thicket of salmonberries crowded the stream, after which lies the tree felled by the property owners.

As was mentioned above, the surrounding property owners take care to keep the channel clear of large woody debris. It was also observed that the groundcover was less dense than upstream, and this was also likely due to the influence of the property owners.

Pebble Counts:

The location of the downstream pebble count was where the first downstream BFW measurement was taken, so approximately 170 feet from the outlet of the crossing at a riffle. The first upstream pebble count was likewise taken at the first upstream BFW measurement, approximately 100 feet from the crossing. The second upstream count was at 130 feet from the crossing and captured the sediment at the widening of the stream located there.

Table 2. Pebble Count results

Locations	Upstream		Downstream
Pebble Count	PC1 (in)	PC2 (in)	PC3 (in)
Diameter Percentile			
D_{95}	2.6	4.4	4.5
D_{84}	1.9	2.4	1.7
D_{50}	1.1	0.7	0.8
D_{16}	0.4	0.0 (1.2 mm)	0.2

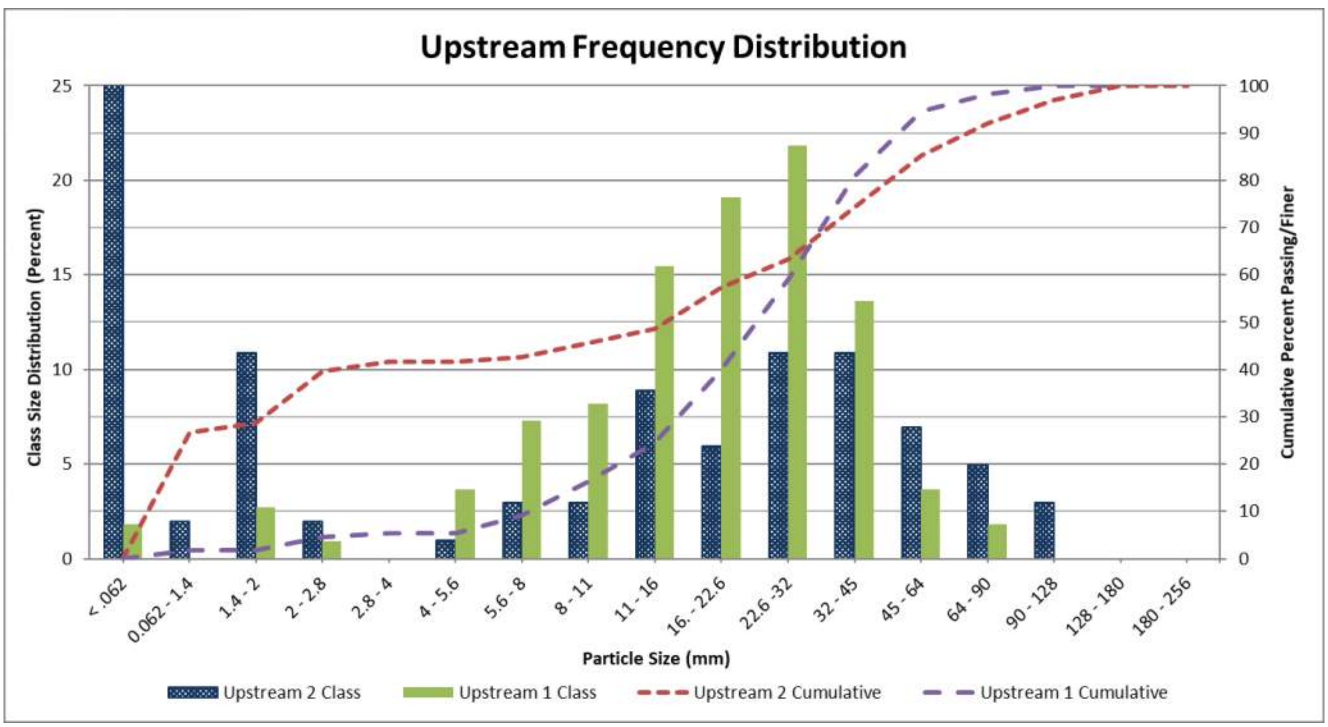


Figure 1. Upstream Pebble Count Gradation

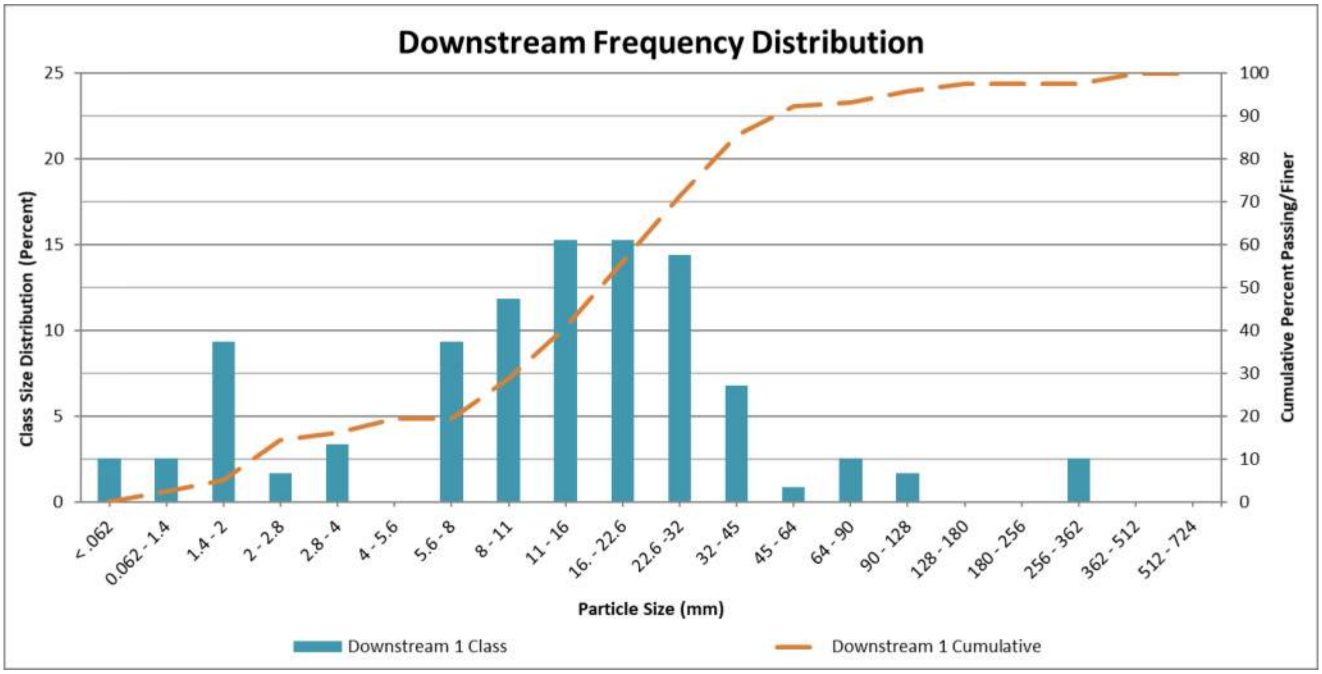


Figure 2. Downstream Pebble Count Gradation

Photos:

Any relevant photographs placed here with descriptions.

Photo 1. Existing culvert inlet

Photo 2. Existing culvert outlet

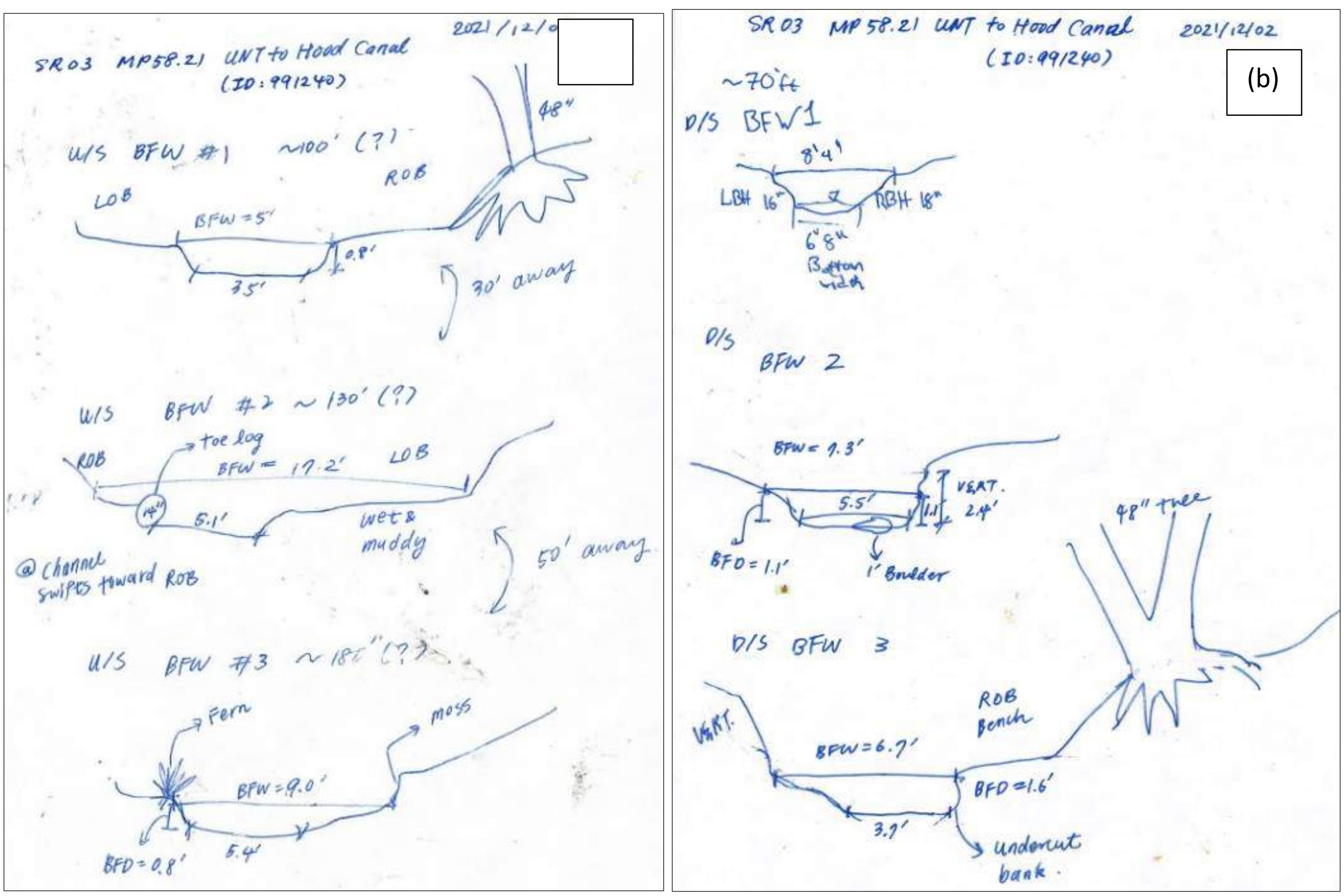


Photo 3. Channel geometry sketches at (a) upstream and (b) downstream BFW locations

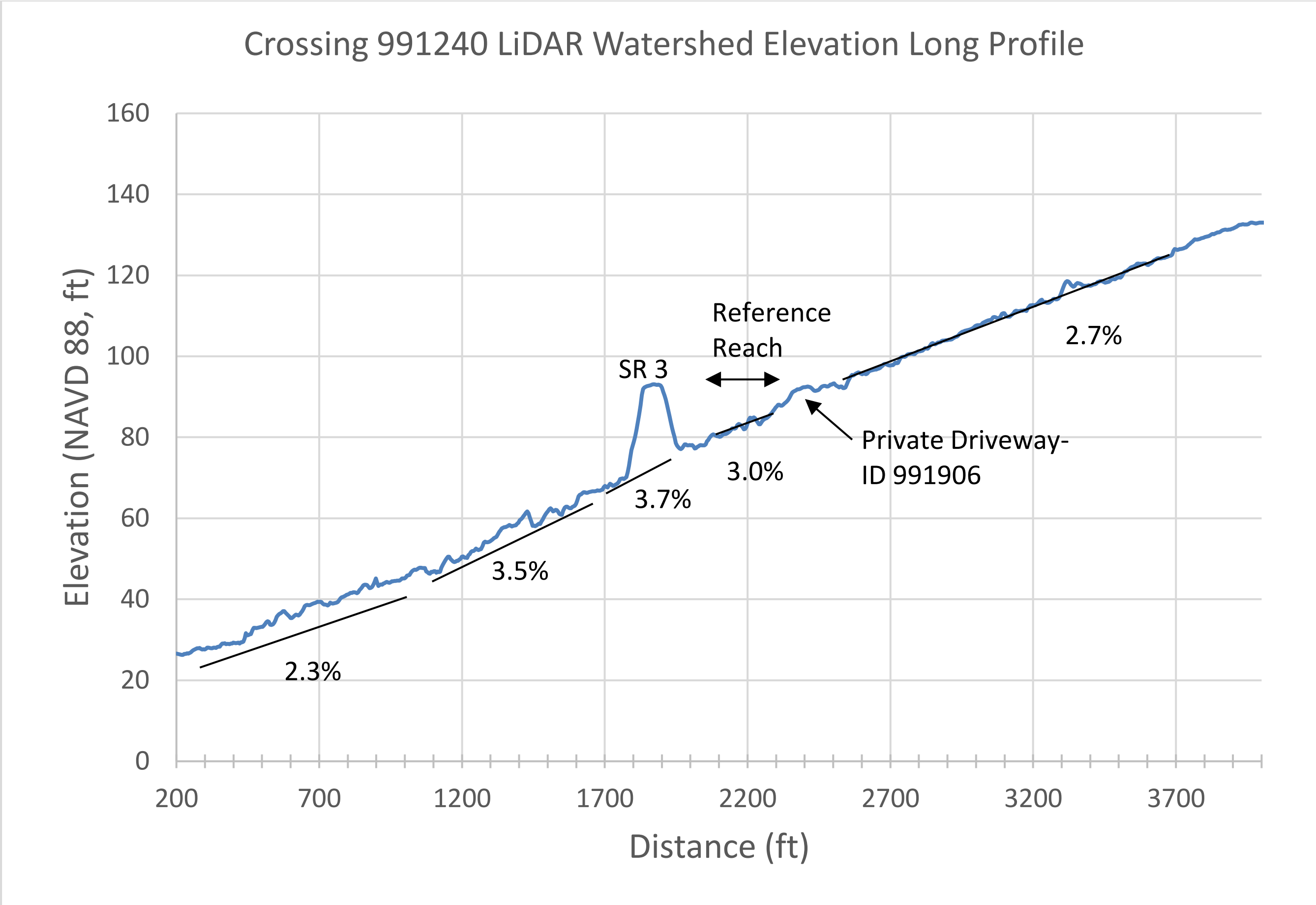


Photo 4. Watershed longitudinal profile

Photo 5. Upstream BFW #1, looking downstream

Photo 6. Upstream BFW #2, looking downstream

Photo 7. Upstream BFW #3, looking upstream

Photo 8. Downstream (a) BFW #1 and (b) BFW #2

Photo 9. Downstream BFW #3

Photo 10. Upstream reach

Photo 11. Main channel flows around a rootwad in upstream reach

Photo 12. Rootwad in the reference reach

Photo 13. Approximately 70 feet upstream of the rootwad, looking downstream

Photo 14. Toe log and scour hole under the trunk in the upstream reach, looking upstream

Photo 15. Approximately 30 feet downstream of the crossing, looking downstream


Photo 16. Channel approximately 100 feet downstream, looking upstream


Photo 17. Vertical banks with no established vegetation indicating active incision in the downstream reach, looking downstream

Photo 18. Downstream reach with incised right bank, looking upstream

Photo 19. Approximately 250 feet downstream, looking downstream

Photo 20. Approximately 350 feet downstream, looking downstream

Photo 21. Downstream reach sediment

Photo 22. Downstream reach sediment, approximately 300 feet downstream

Samples:				
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx				
Were any sample(s) collected from below the OHWM?	*No ☐ If no, then stop here.* *Yes ☐ If yes, then fill out the proceeding section for each sample.*			
Sample #:	Work Start:	Work End:	Latitude:	Longitude:
Summary/description of location: Summarize/describe the sample location.				
Description of work below the OHWL: *Describe the work below the OHWL, including equipment used and quantity of sediment sampled.*				
Description of problems encountered: *Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.*				

Concurrence Meeting

Concurrence Meeting	Date: Feb 2, 2022	Time of Arrival: 12:30 PM
Prepared By: C Nicol, S Sheldon	Weather: Partly cloudy	Time of Departure: 2:30 PM

Attendance List:

Name	Organization	Role
Kate Fauver	WSDOT	Transportation Planner
Alison O'Sullivan	Suquamish Tribe	Biologist
Damon Romero	WSDOT	Biologist
Dave Molenaar	WSDOT	Habitat Biologist
Heather Pittman	WSDOT	State Hydraulic Engineer
Amber Martens	WDFW	Biologist
Shawn Stanley	WDFW	Habitat Engineer
Marla Powers	Port Gamble S'Klallam Tribe	Environmental Planner
Hunter Henderson	WSDOT	Transportation Specialist
Colin Nicol	PACE	Environmental Scientist
Shane Sheldon	PACE	Engineer

Bankfull Width:

Summarize on-site discussion, describe measurements, and concurrence or decisions made that help to inform the design.

- PACE explained the noted bank instability and apparent incision near the crossing outlet, the group agreed and moved to downstream end of survey to take BFW measurements.
- Downstream of the crossing the concurrence group measured: 9.0 ft, 6.0 ft, 7.0 ft.
- Upstream of the crossing the concurrence group did not measure any BFWs because we were upstream of the tributary junction, meaning there is a smaller drainage area.
- The group agreed the upstream reach would be preferable for the reference reach, but the downstream should be used for the bankfull width measurements
  - The agreed plan is to take the cross-section from upstream, but scale it up using the bankfull width measurements from downstream

Table 3. All bankfull width measurements and average agreed to during the concurrence meeting

	Approximate Distance from Crossing (ft)	Bankfull Width (ft)	Used in average	Source/Date
U/S BFW #1	100 (upstream)	5.0	N	PACE (December 2021)
U/S BFW #2	130 (upstream)	17.2	N	PACE (December 2021)
U/S BFW #3	180 (upstream)	9.0	N	PACE (December 2021)
D/S BFW #1	~170 (downstream)	8.3	Y	PACE (December 2021)
D/S BFW #2	~240 (downstream)	7.3	Y	PACE (December 2021)
D/S BFW #3	~320 (downstream)	6.7	Y	PACE (December 2021)
	~240 (downstream)	9.0	Y	Concurrence site visit (February 2022)
	~260 (downstream)	6.0	Y	Concurrence site visit (February 2022)
	~280 (downstream)	7.0	Y	Concurrence site visit (February 2022)
	Average	**7.4**		

Reference Reach:

Summarize on site discussion, concurrence and/or appropriateness of selected reference reach.

- The group agreed that upstream would likely provide the better reference reach.
- Group looked at spot of 17.2 ft measurement from SV#2 and agreed it should not be used in average. Saturated bench from hillslope seepage not from streamflow.
- Group agreed that the channel geometry should be used from the upstream reference reach, but the channel cross-section should be scaled to match the BFW of the downstream reach.
- The tributary junction just upstream of the crossing means the reference is slightly undersized, so the downstream BFWs should be used.

Observations:

Summarize on site discussions, any perceived/known project constraints, or other details that help to inform the design.

- The landowners on the downstream side of the crossing are protective of their land and should be contacted prior to entry.

Photos:

Any relevant photographs placed here with descriptions.

Photo 23. Concurrence group at the outlet of the crossing

Photo 24. Concurrence group in the downstream reach, captured with a wide angle camera

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	Unnamed Tributary (UNT) to Hood Canal
WDFW SITE ID:	991240
STATE ROUTE/MILEPOST:	SR 003 / MP58-21
SITE VISIT DATE:	12/02/2021
ATTENDEES:	Shane Sheldon (PE, PACE), Colin Nicol (Environmental Scientist, PACE), Tasha Wang (PE, PACE), Henry Moen (EIT, PACE)
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - **Low/Medium/High** (***additional considerations or red flags may trigger the need for new discussions***):	Low. The proposed channel will maintain the existing channel alignment. The crossing has a somewhat steeper slope that the upstream reach. Some distinct incision was observed in the downstream reach, and the main concern is that if the crossing is opened up a small headcut/incision could migrate upstream. The slope ratio comparing the reference reach to the project crossing will likely be greater than 1, but not excessively so. The survey data is not yet available but will determine the final slope ratio. The highway crossing is at the channels natural transition to a more confined ravine. Stream simulation design is likely achievable, but the reference reach is somewhat unconfined. Based on the reasons above, the complexity of this project is low with main concern being the recent observed incision downstream.
IN WATER WORK WINDOW	August 1 – August 15

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, “Is follow-up needed on this item?” The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading	X			Limited channel regrade outside of the crossing
Risk of degradation/aggradation		X		Incision and channel widening were observed in the downstream reach.
Channel realignment	X			Valley location set
Expected stream movement	X			Some bank instability observed but active channel confined in valley
Gradient		X		Crossing is over 3% slope
Potential for backwater impacts	X			No risk of backwater impacts
Meeting requirements for freeboard	X			High roadway prism
Stream size, and Bankfull Width		X		The channel becomes more confined moving downstream with the crossing located at a transition area
Slope ratio		X		Likely steeper through the crossing that upstream. Survey data will be used to determine the final slope ratio.
Sediment supply	X			No evident excess supply
Meeting stream simulation	X			No issues anticipated
Channel confinement	X			Less confined upstream than downstream
Geotech or seismic considerations	X			None anticipated
Tidal influence	X			No
Alluvial fan	X			No
Fill depth above barrier	X			No issues anticipated
Presence of other nearby barriers	X			None
Presence of nearby infrastructure	X			None
Need for bank protection	X			Some bank instability noted but at valley bottom, away from any infrastructure

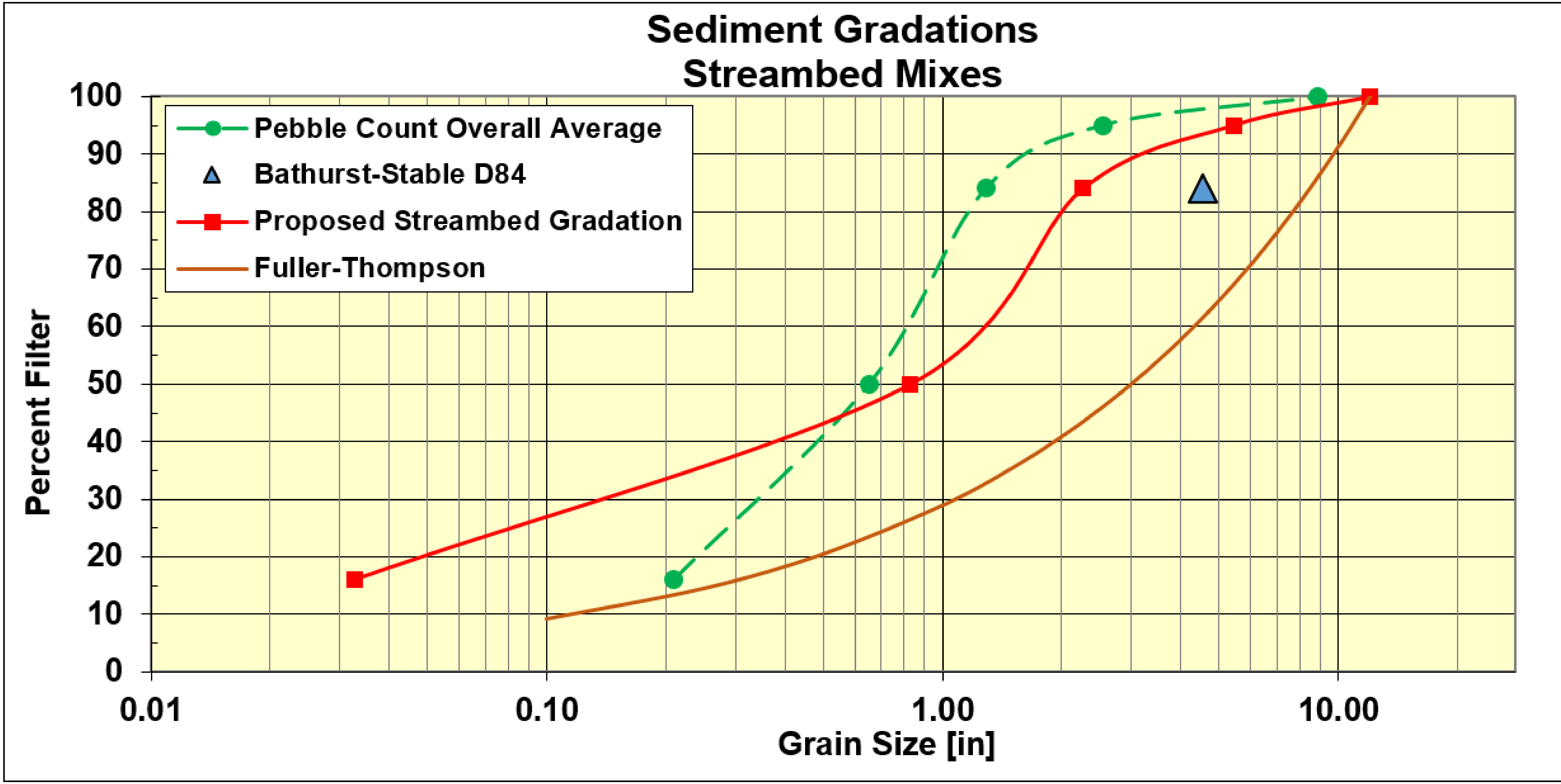
Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Floodplain utilization ratio		X		Needs to be analyzed using 2-D hydraulic model. Less confined upstream than downstream.
Other:	N/A			

Appendix C: Streambed Material Sizing Calculations

DRAFT

Comparison of Existing and Proposed Gradations



Determining Aggregate Proportions

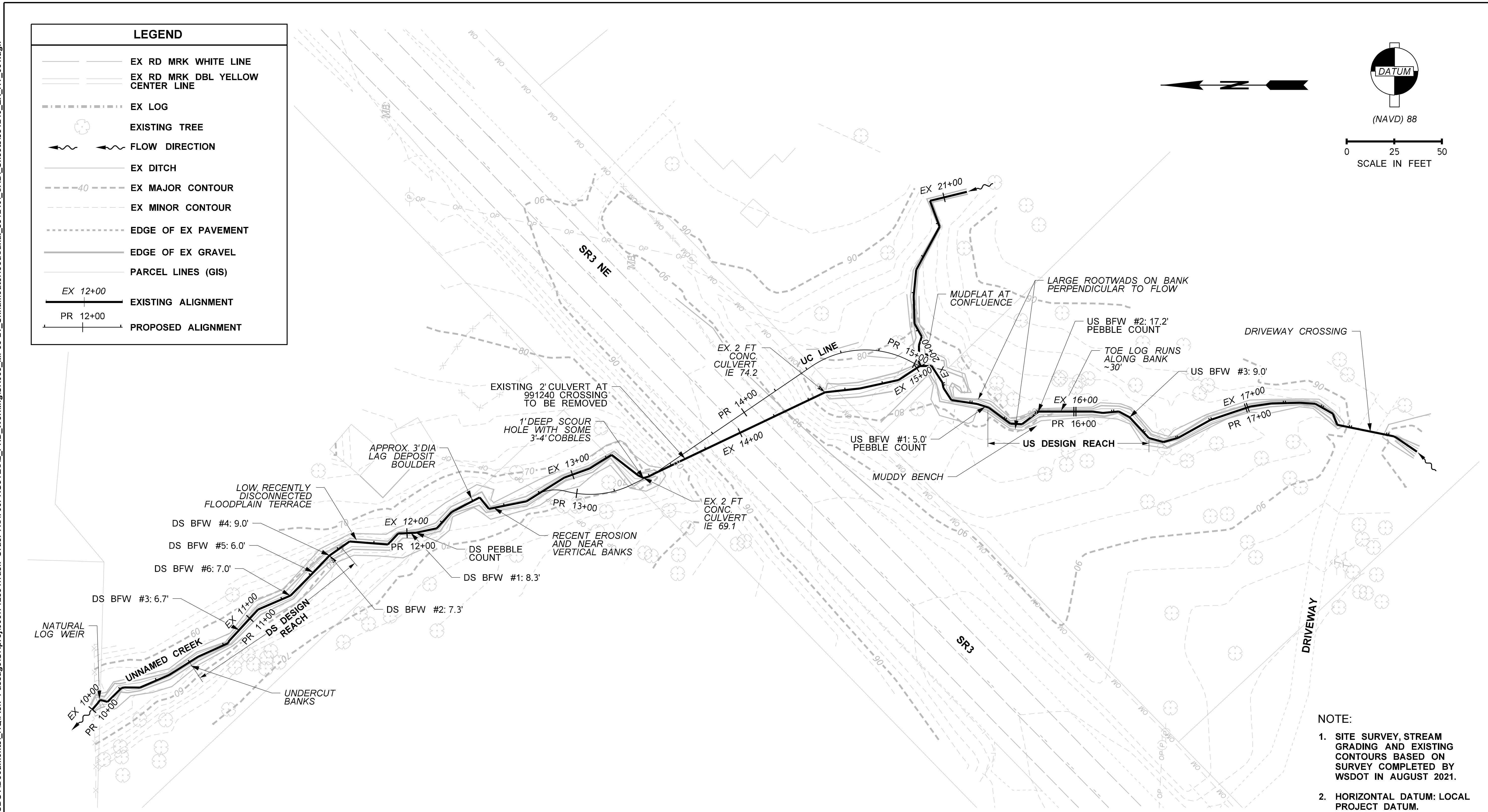
Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobble Mixes 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	**914**									**100**	**100.0**
32.0	**813**									50	**100.0**
28.0	**711**								**100**		**100.0**
23.0	**584**								50		**100.0**
18.0	**457**							**100**			**100.0**
15.0	**381**							50			**100.0**
12.0	**305**						**100**				**100.0**
10.0	**254**					**100**	**80**				**98.0**
8.0	**203**				**100**	**80**	68				**96.8**
6.0	**152**			**100**	**80**	68	57				**95.7**
5.0	**127**			**80**	68	57	**45**				**94.5**
4.0	**102**		**100**	71	57	**45**	39				**93.9**
3.0	**76.2**		**80**	63	**45**	38	34				**93.4**
2.5	**63.5**	**100**	65	54	37	32	28				**92.8**
2.0	**50.8**	**80**	50	**45**	29	25	22				**74.2**
1.5	**38.1**	73	**35**	32	21	18	16				**66.9**
1.0	**25.4**	**65**	20	18	13	12	11				**59.6**
0.75	**19.1**	50	**5**	**5**	**5**	**5**	**5**				**45.5**
No. 4 =	**4.75**	**35**									**31.5**
No. 40 =	**0.425**	**16**									**14.4**
No. 200 =	**0.0750**	**7**									**6.3**
% per category		**90**	**0**	**0**	**0**	**0**	**10**	**0**	**0**	**0**	*--> 100%*
% Cobble & Sediment		**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	*100.0%*

Proposed Streambed Gradation	in	mm	**Bathurst Mobility** in	mm	**Pebble Count Overall Average**	in	mm
D16	0.03	0.83	-	-	D16	0.2	5.32
D50	0.8	21.08	-	-	D50	0.7	16.58
D84	2.3	57.49	**4.5**	115.04	D84	1.3	32.71
D95	5.4	137.89	-	-	***D95***	2.5	64.42
D100	12.0	304.80	-	-	D100	8.9	226.17

Appendix D: Stream Plan Sheets, Profile, Details

DRAFT



NOTE:

1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN AUGUST 2021.
2. HORIZONTAL DATUM: LOCAL PROJECT DATUM.

PRELIMINARY

NOT FOR CONSTRUCTION

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DESIGNED BY	J KALLSTROM
ENTERED BY	R VANDYKE
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3
UNNAMED TO HOOD CANAL
FISH BARRIER 991240 DESIGN

EXISTING STREAM PLAN

PLAN REF NO HY01

SHEET 1 OF 4 SHEETS

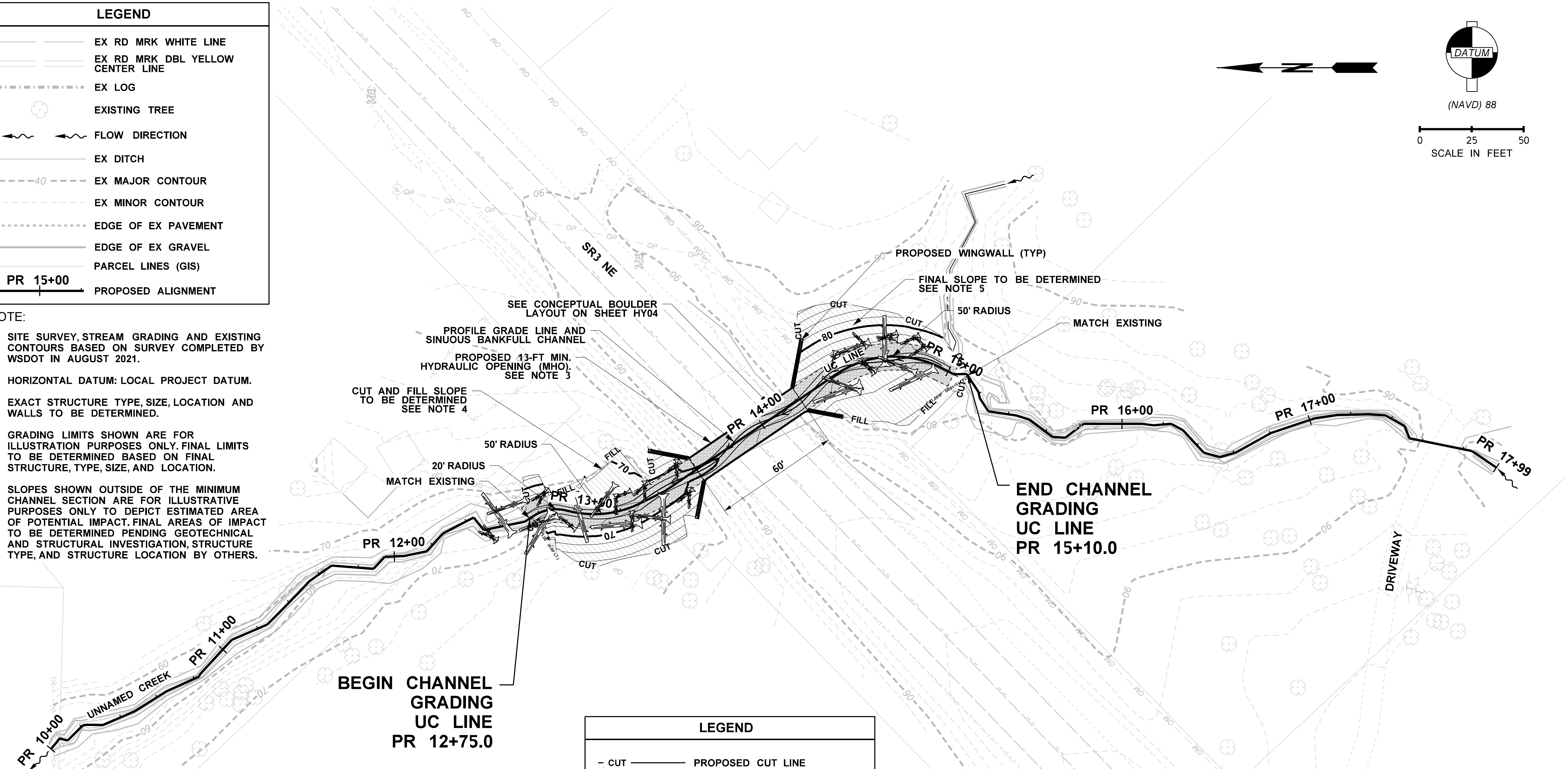
pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJ\TEC\12_PHD_Working\SR003_MP58-21_UnnamedtoHoodCanal_991240_CAD_Sheets\991240_PS_HY_002.dgn

LEGEND

- EX RD MRK WHITE LINE
- EX RD MRK DBL YELLOW CENTER LINE
- EX LOG
- EXISTING TREE
- FLOW DIRECTION
- EX DITCH
- 40 — EX MAJOR CONTOUR
- EX MINOR CONTOUR
- EDGE OF EX PAVEMENT
- EDGE OF EX GRAVEL
- PARCEL LINES (GIS)
- PR 15+00 — PROPOSED ALIGNMENT

NOTE:

1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN AUGUST 2021.
2. HORIZONTAL DATUM: LOCAL PROJECT DATUM.
3. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.
4. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE, AND LOCATION.
5. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION BY OTHERS.



LOG SCHEDULE

- TYPE 1 LOG: 2' DBH, 25' L, W/ROOTWAD (8 TOTAL)
- TYPE 2 LOG: 1.5' DBH, 20' L, W/ROOTWAD (7 TOTAL)
- TYPE 3 LOG: 1' DBH, 10' L, W/ROOTWAD (23 TOTAL)

LEGEND

- CUT — PROPOSED CUT LINE
- 40 — PROPOSED MAJOR CONTOUR
- PROPOSED MINOR CONTOUR
- PROPOSED STREAMBED MIX
- ESTIMATED AREA OF POTENTIAL IMPACT, SEE NOTE 5
- 28" TO 36" HABITAT BOULDERS
- PROPOSED STRUCTURE
- PROPOSED WINGWALL

PRELIMINARY

NOT FOR CONSTRUCTION

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PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

Washington State Department of Transportation

SR 3
UNNAMED TO HOOD CANAL
FISH BARRIER 991240 DESIGN

STREAM RESTORATION PLAN

PLAN REF NO HY02

SHEET 2 OF 4 SHEETS

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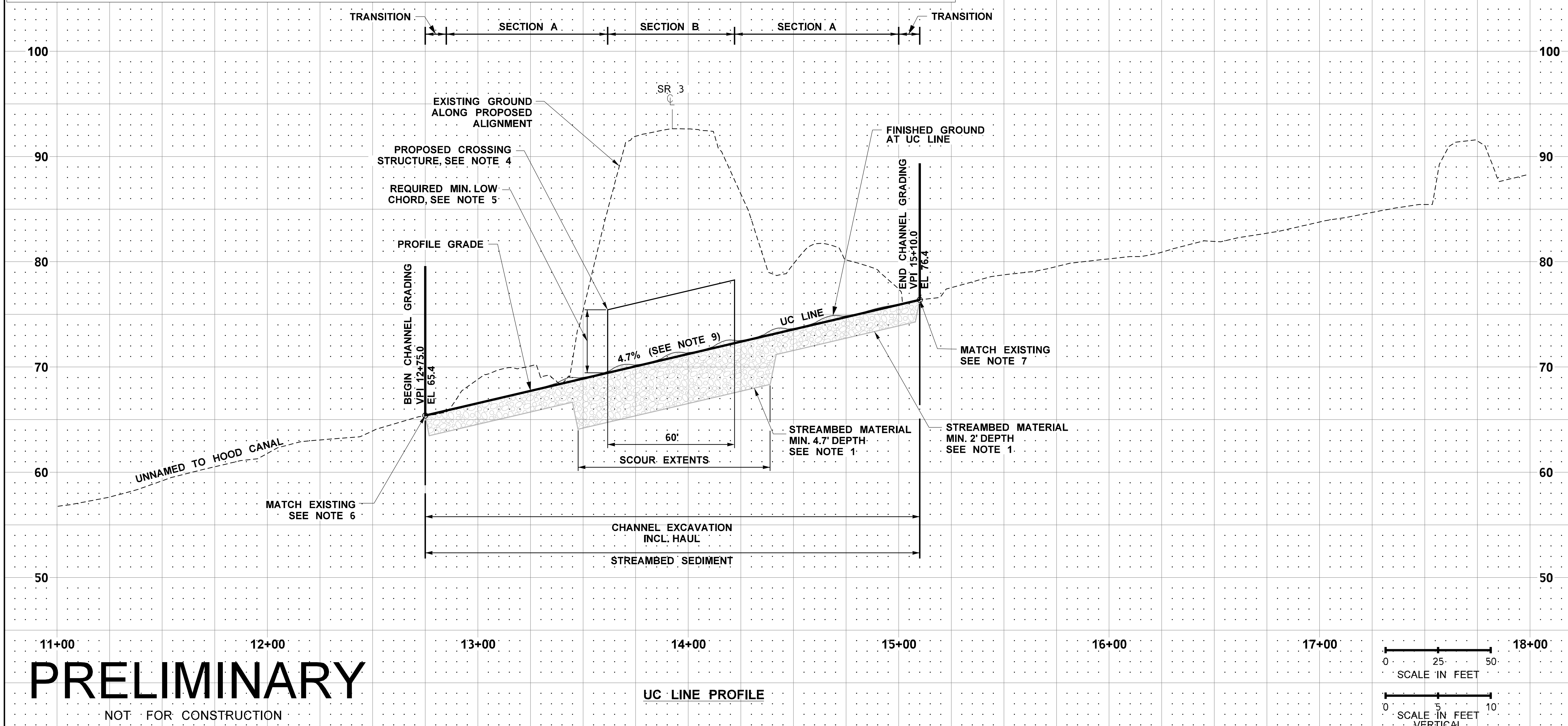
NOTES:

1. PRELIMINARY MATERIAL DEPTH WITHIN THE SCOUR EXTENTS IS TOTAL SCOUR DEPTH, AND 2' MINIMUM OUTSIDE OF THE SCOUR EXTENTS. FINAL MATERIAL DEPTHS AND EXTENTS TO BE DETERMINED PENDING STRUCTURE FOUNDATION TYPE AND LOCATION.
2. TWO-MAN HABITAT BOULDERS WILL BE A MINIMUM 70 PERCENT BURIED.
3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED. ALL STRUCTURAL ELEMENTS, INCLUDING ANY SOIL RELIED ON FOR LATERAL FOUNDATION SUPPORT, MUST BE OUTSIDE OF STRUCTURE FREE ZONE.
5. THE REQUIRED FREEBOARD FOR THE SR 3 CROSSING IS 2 FEET FROM 100YR WSE. 10 FEET OF CLEARANCE FROM THE HIGHEST STREAMBED GROUND IS RECOMMENDED.
6. FROM PR 12+75 TO PR 12+85, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
7. FROM PR 15+00 TO PR 15+10, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
8. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
9. THE PROFILE GRADE OF 4.7% IS ALONG THE PROPOSED UC LINE ALIGNMENT WHICH IS PARALLEL TO THE PROPOSED CROSSING WITH A LENGTH OF 235'. THE ACTUAL SINUOUS BANKFULL CHANNEL LENGTH IS 237.28 FT WITH AN AVERAGE SLOPE OF 4.6%.

DATUM (NAVD) 88



UC LINE PROFILE

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DATE	2/20/2023			
PLOTTED BY	jgerman			
DESIGNED BY	J KALLSTROM			
ENTERED BY	R VANDYKE			
CHECKED BY				
PROJ. ENGR.				
REGIONAL ADM.		REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3
UNNAMED TO HOOD CANAL
FISH BARRIER 991240 DESIGN

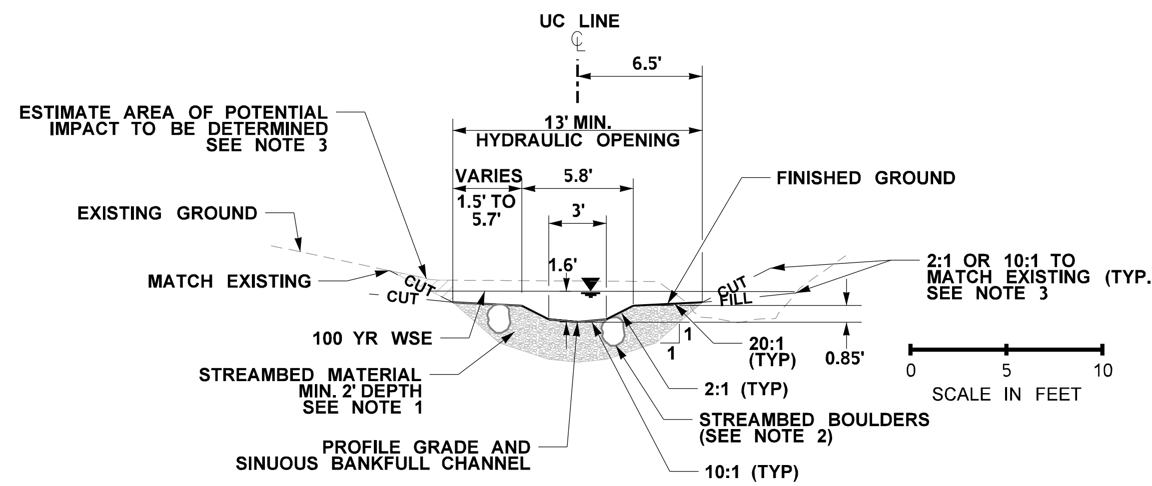
STREAM RESTORATION PROFILE

PLAN REF. NO. HY03

SHEET 3 OF 4 SHEETS

DATUM

(NAVD) 88

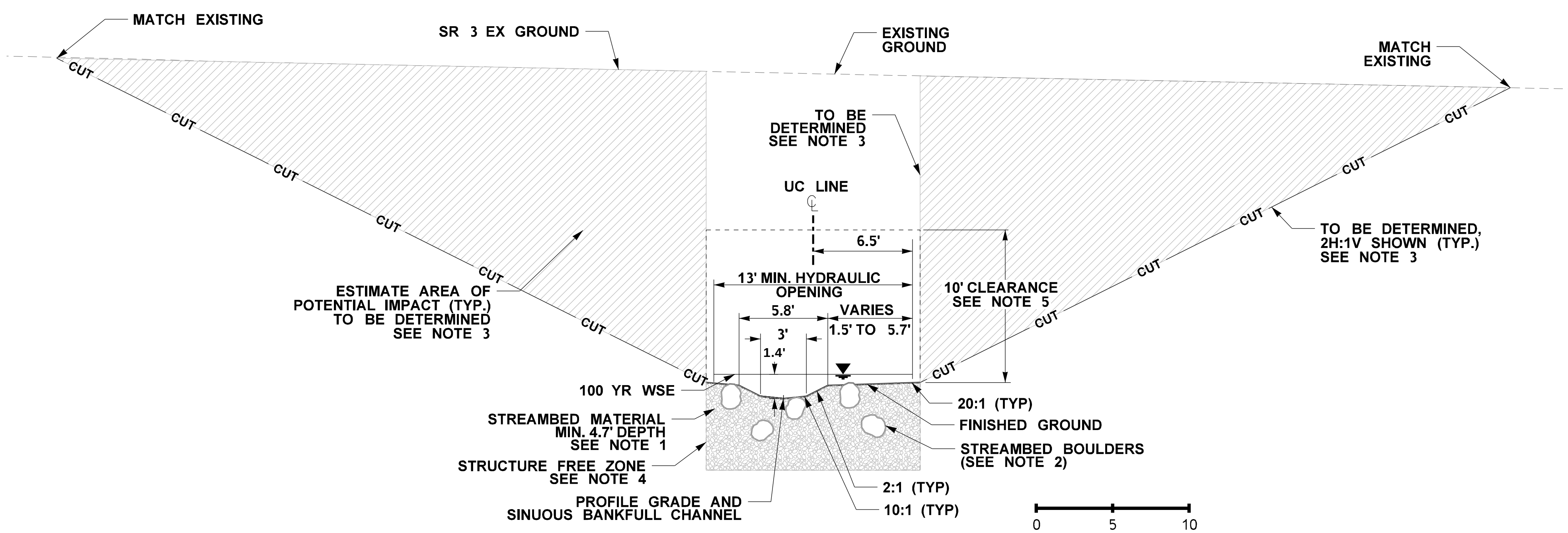


UNT TO HOOD CANAL- LINE UC

TYPICAL SECTION
SECTION A
PR 12+75 TO PR 13+61
PR 14+22 TO PR 15+10
LOOKING DOWNSTREAM

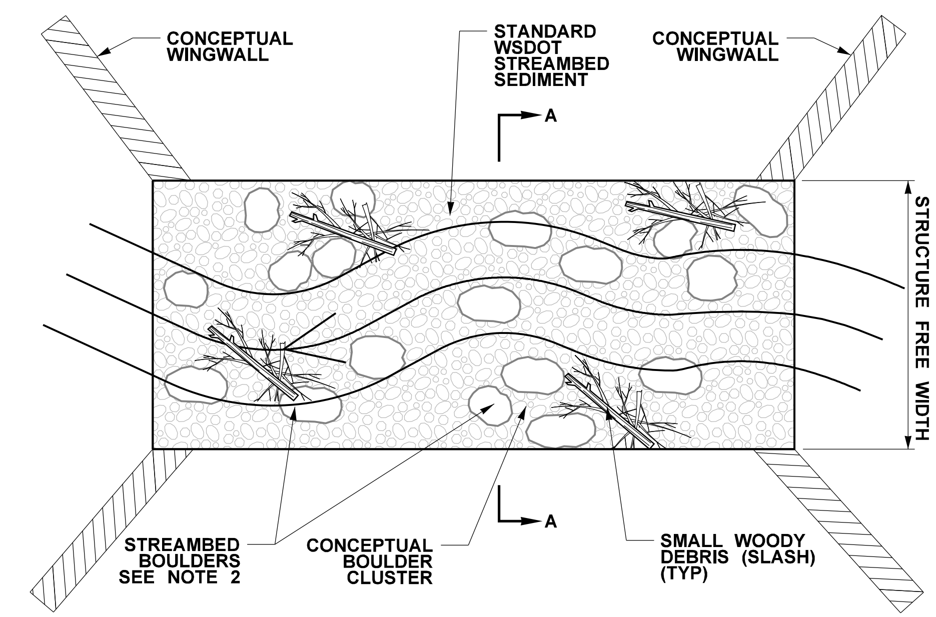
NOTES:

1. PRELIMINARY MATERIAL DEPTH WITHIN THE SCOUR EXTENTS IS TOTAL SCOUR DEPTH, AND 2' MINIMUM OUTSIDE OF THE SCOUR EXTENTS. FINAL MATERIAL DEPTHS AND EXTENTS TO BE DETERMINED PENDING STRUCTURE FOUNDATION TYPE AND LOCATION.
2. TYPE TWO STREAMBED BOULDERS ARE PROPOSED TO BE A MINIMUM 70 PERCENT BURIED
3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED. ALL STRUCTURAL ELEMENTS, INCLUDING ANY SOIL RELIED ON FOR LATERAL FOUNDATION SUPPORT, MUST BE OUTSIDE OF STRUCTURE FREE ZONE.
5. THE REQUIRED FREEBOARD FOR THE SR 3 CROSSING FROM THE 100YR WSE IS 1 FOOT AND THE REQUIRED CLEARANCE FROM THE HIGHEST STREAMBED ELEVATION IS 10 FEET.
6. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
7. FROM PR 12+75 TO PR 12+85, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
8. FROM PR 15+00 TO PR 15+10, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.



UNT TO HOOD CANAL - LINE UC

A-A
TYPICAL SECTION
SECTION B
PR 13+61 TO PR 14+22
LOOKING DOWNSTREAM



CONCEPTUAL BOULDER LAYOUT

NOT TO SCALE

PRELIMINARY

NOT FOR CONSTRUCTION

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR003_MP58-21_UnnamedtoHoodCanal_991240_CAD_Sheets\991240_DE_HY_004.dgn

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DATE	2/20/2023
PLOTTED BY	jgerman
DESIGNED BY	J KALLSTROM
ENTERED BY	R VANDYKE
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

Washington State Department of Transportation

SR 3
UNNAMED TO HOOD CANAL
FISH BARRIER 991240 DESIGN

STREAM RESTORATION SECTION/DETAIL

PLAN REF NO HY04

SHEET 4 OF 4 SHEETS

Appendix E: Manning's Calculations

DRAFT

ROUGHNESS ESTIMATION FOR THE UNNAMED TRIBUTARY TO HOOD CANAL

CALCULATIONS AND TABULAR GUIDES

ROUGHNESS ESTIMATION FOR EXISTING CHANNEL

EXISTING CHANNEL

Stream Channel Flow Resistance Coefficient Computation Tool **(version 1.1, 2-2018)**

Stream Name:	Unnamed Trib to Hood Canal	**Reach:**	991240
Stream Slope, *S* (ft/ft):	0.03500	**Date:**	5/5/2022
		Practitioner:	Josh Kallstrom

Reach D_{50}, D_{84} (mm):	27.1	49	**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (ft):	2.05			
Mean Flow Depth, *d* (ft)[(b)]:	0.53			
Bedform Variation, σ_z (ft)[(c)]:				
Median Thalweg Depth, h_m (ft)[(c)]:				
Large Wood in Steps? (y/n)[(c)]:				

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

See Page 5

See Pages 6 and 7

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.060	0.330	Y
Estimate from Photographic Guidance:	0.060	0.330	y

Instructions: **(See technical summary report, TS-103, for more detailed instructions and references.)**

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

EXISTING CHANNEL

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: Unnamed Trib to Hood Canal
Slope, *S* (ft/ft): 0.03500

Reach: 991240
Date: 5/5/2022
Practitioner: Josh Kallstrom

D_{50}, D_{84}, $D_{84,\ step}$ (m):	0.02	0.05	----
R (ft, m):	2.05	0.62	
d (ft^2, m^2):	0.53	0.16	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average n:	0.060
f:	0.371
Quantitative Average n [1]:	0.057
f [1]:	0.377
Arcement and Schneider (1989) n:	0.069
f:	0.437

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)
$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

n_b [2]	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
0.026	0.011	0.002	0.015	0.015	1	0.069	y
Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate n	Estimate f	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. [3]	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	3.18	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) [4] [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	3.18	0.043	0.172	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	y
Jarrett (1984) [ave. std. error = 28%]	n/a	0.097	0.868	75	0.002 to 0.039	n/a	y
Griffiths (1981); rigid bed [R^2=0.59]	27.3	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	12.3	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	12.3	0.031	0.090	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	y

EXISTING CHANNEL = 0.06

Table 4A-2 Manning's Roughness Coefficients for Stream Channels

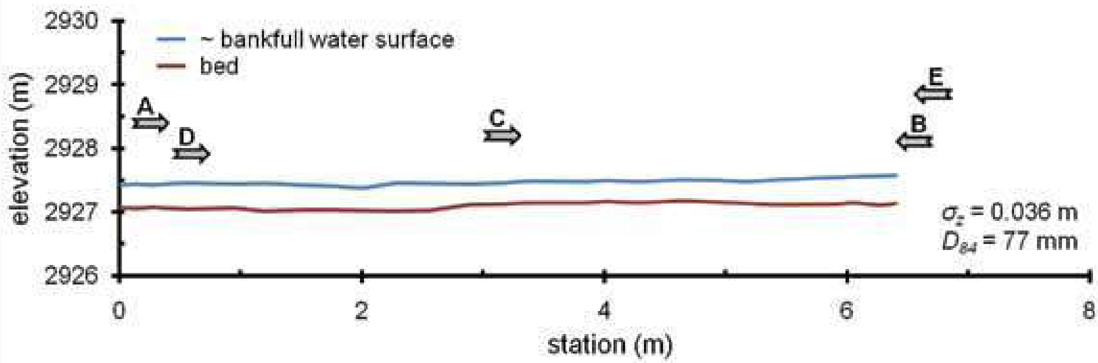
Stream Channels		Manning's n
Minor streams (surface width at flood stage less than 100 feet):		
1. Fairly regular section:		
a.	Some grass and weeds, little or no brush	0.030-0.035
b.	Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
c.	Some weeds, light brush on banks	0.035-0.05
d.	Some weeds, heavy brush on banks	0.05-0.07
e.	Some weeds, dense willows on banks	0.06-0.08
f.	For trees within channel, with branches submerged at high stage, increase all above values by 0.01–0.02	
2. Irregular sections, with pools, slight channel meander; increase values g		**+0.01 due to some branches and brush in channel**
3. Mountain streams, no vegetation in channel, banks usually steep, trees high stage:		
a.	Bottom of gravel, cobbles, and few boulders	0.04-0.05
b.	Bottom of cobbles, with large boulders	0.05-0.07
Floodplains (adjacent to natural streams):		
1. Pasture, no brush:		
a.	Short grass	0.030-0.035
b.	High grass	0.035-0.05
2. Cultivated areas:		
a.	No crop	0.03-0.04
b.	Mature row crops	0.035-0.045
c.	Mature field crops	0.04-0.05
3. Heavy weeds, scattered brush		0.05-0.07
4. Light brush and trees:		
a.	Winter	0.05-0.06
b.	Summer	0.06-0.08
5. Medium to dense brush:		
a.	Winter	0.07-0.11
b.	Summer	0.10-0.16
6. Dense willows, summer, not bent over by current		0.15-0.20
7. Cleared land with tree stumps, 100 to 150 per acre:		
a.	No sprouts	0.04-0.05
b.	With heavy growth of sprouts	0.06-0.08
8. Heavy stand of timber, a few down trees, little undergrowth:		
a.	Flood depth below branches	0.10-0.12
b.	Flood depth reaches branches	0.12-0.16

Major streams (surface width at flood stage more than 100 feet): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited if possible. The value of n for larger streams of most regular sections, with no boulders or brush, may be in the range of 0.028–0.033.


ESL-6 (plane-bed)
East Saint Louis Creek, Colorado, USA
S = 0.024 m/m; W = 3.0 m (9.8 ft); L = 6.4 m (21 ft)
A
B
7/12/2007
mid flow
low flow
mid flow
7/14/2008
C
8/13/2007
Fraser Experimental Forest;
Arapaho-Roosevelt National Forest
stream classification (Rosgen): B3

ESL-6

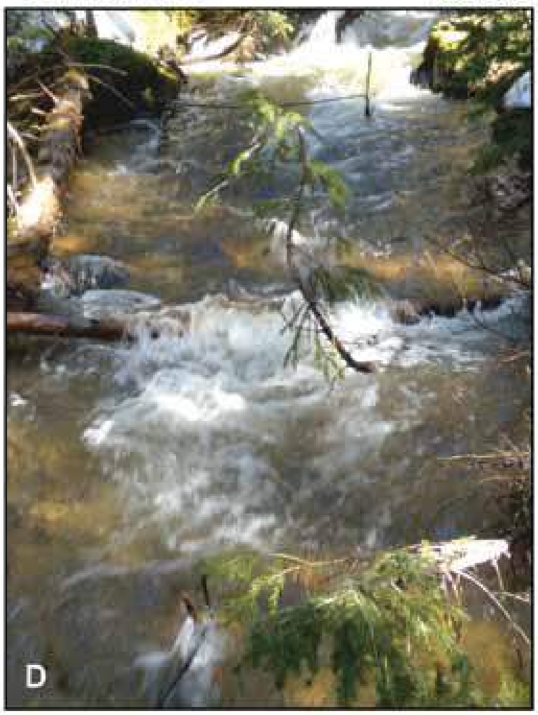
longitudinal profile



~ bankfull flow	**mid flow**	**low flow** (facing page)
***n* = 0.048**	***n* = 0.078**	***n* = 0.099**
***f* = 0.28**	***f* = 0.76**	***f* = 1.4**
	31 m/s (2.0 ft/s)	V = 0.39 m/s (1.3 ft/s)
	32 cms (11 cfs)	Q = 0.099 cms (3.5 cfs)
	24 m (0.79 ft)	R = 0.15 m (0.49 ft)
	9 m (9.3 ft)	W = 2.7 m (8.7 ft)
	37	Fr = 0.31

Raise to 0.6 because smaller stream and higher gradient stream

~ bankfull flow 6/9/2008



mid flow 7/14/2008

PROPOSED CHANNEL = 0.065 INCREASE TO ACCOUNT FOR LWM IN CHANNEL

ROUGHNESS ESTIMATION FOR FOREST

Computed roughness coefficient: $\boxed{\text{Manning's } n=0.20}$
Date of flood: March 3, 1971
Date of photograph: March 29, 1979
Depth of flow on flood plain: 2.9 ft
Description of flood plain: The vegetation of the flood plain is a mixture of large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities. Obstructions are minor. Ground cover is medium, and the large amount of undergrowth includes vines and palmettos. Veg_d=0.0115, and C_*=22.7. The selected values are n_b=0.025, n_1=0.005, n_3=0.010, n_4'=0.015, and n_0=0.055.

Figure 19. Thompson Creek near Clara, Miss. (Colson, Ming, and Arcement, 1979b, HA–597, cross section 9).

Appendix F: Large Woody Material Calculations

DRAFT

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	SR 3 MP 58.21		Key piece volume	1.310	yd3
Stream name	UNT to Hood Canal		Key piece/ft	0.0335	per ft stream
length of regrade[a]	231	ft	Total wood vol./ft	0.3948	yd3/ft stream
Bankfull width	7.4	ft	Total LWM[c] pieces/ft stream	0.1159	per ft stream
Habitat zone[b]	Western WA				

Log type	Diam at midpoint *	Length [d]	Volume/log [d]	Rootwad?	Qualifies as key piece?	No. LWM pieces	Total wood volume
	ft	ft	yd3				yd3
1	2.00	25	2.91	yes	yes	8	23.27
2	1.50	20	1.31	yes	no	7	9.16
3	1.00	10	0.29	yes	no	23	6.69
4			0.00	no			0.00
5			0.00	no			0.00
6			0.00				0.00
7			0.00				0.00
8			0.00				0.00
9			0.00				0.00
10			0.00				0.00

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	8	38	39.1
75% Targets	8	27	91.2
50% Targets	4	20	47.0
	on target	surplus	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)

Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)

Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

Appendix G: Future Projections for Climate-Adapted Culvert Design

DRAFT

Future Projections for Climate-Adapted Culvert Design

Project Name:

Stream Name:

Drainage Area: 484 ac

Projected mean percent change in bankfull flow:

2040s: 12.4%

2080s: 14.5%

Projected mean percent change in bankfull width:

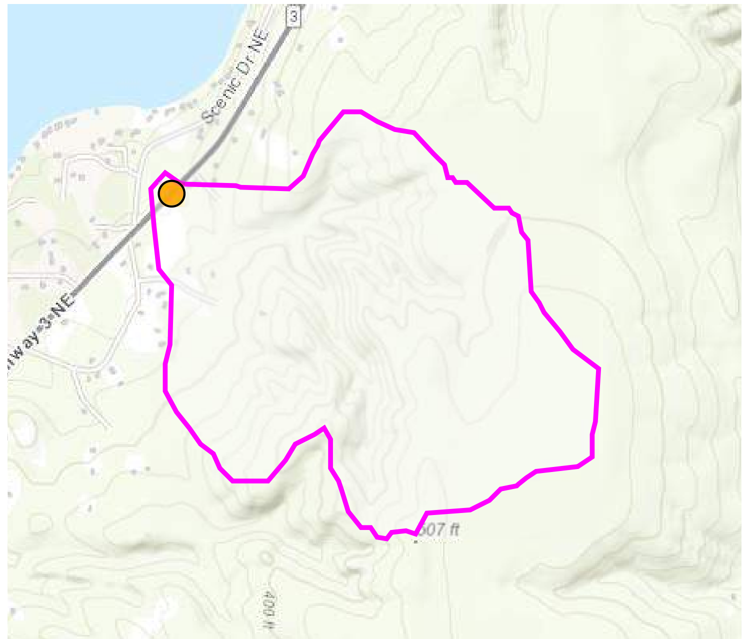
2040s: 6%

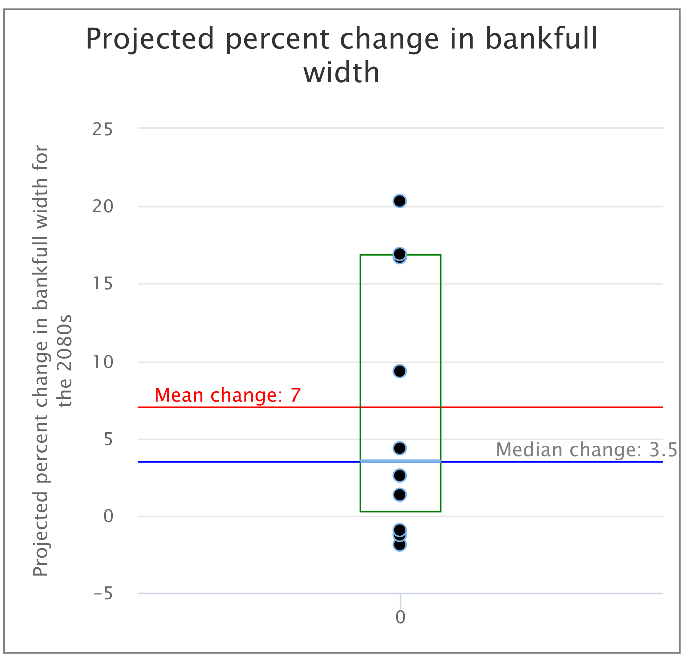
2080s: 7%

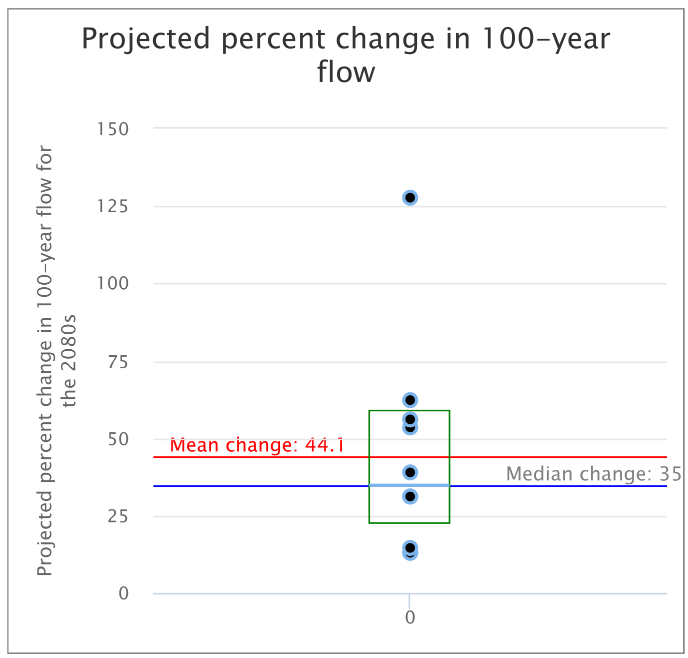
Projected mean percent change in 100-year flood:

2040s: 28.1%

2080s: 44.1%





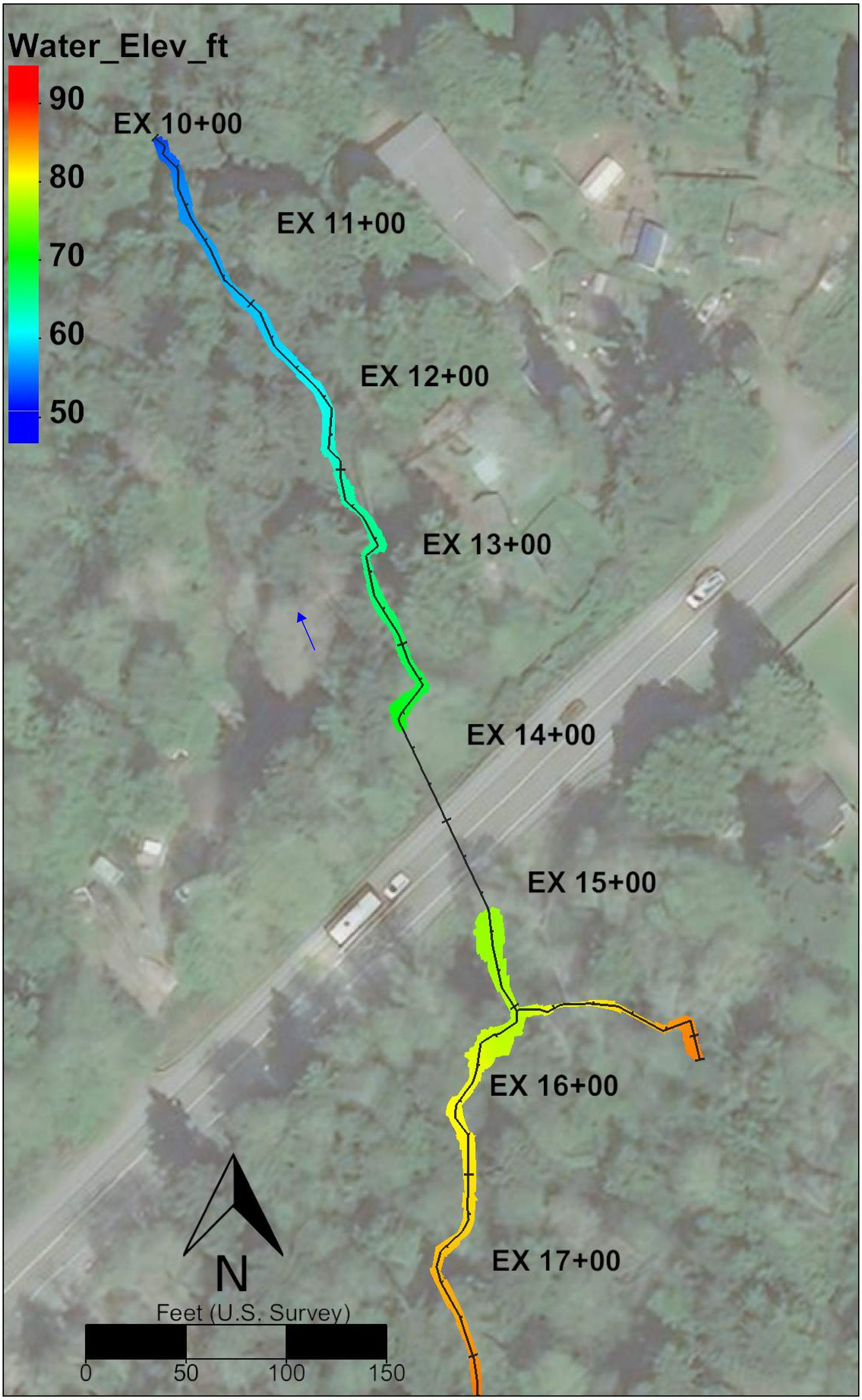


Black dots are projections from 10 separate models

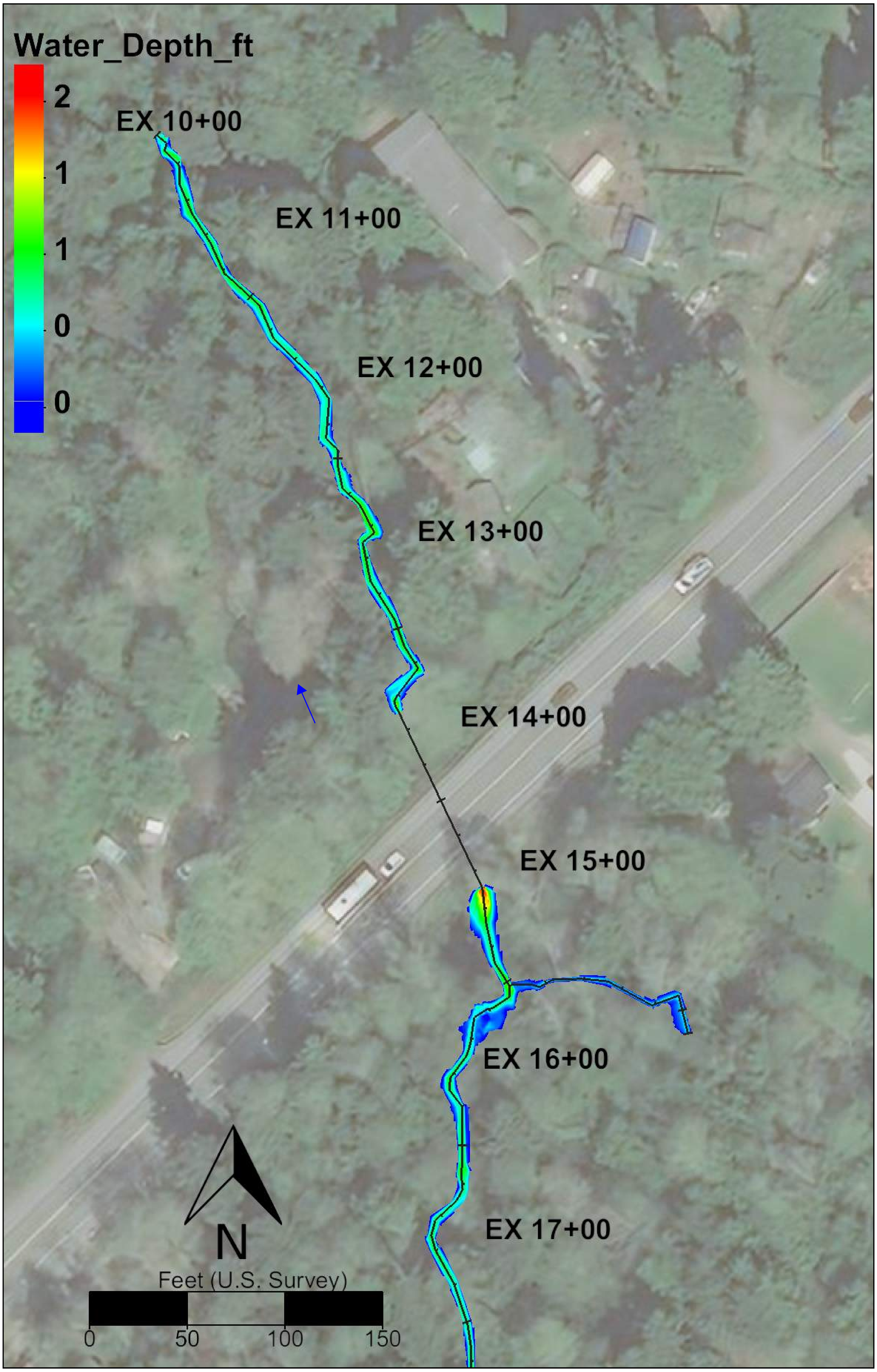
The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

Appendix H: SRH-2D Model Results

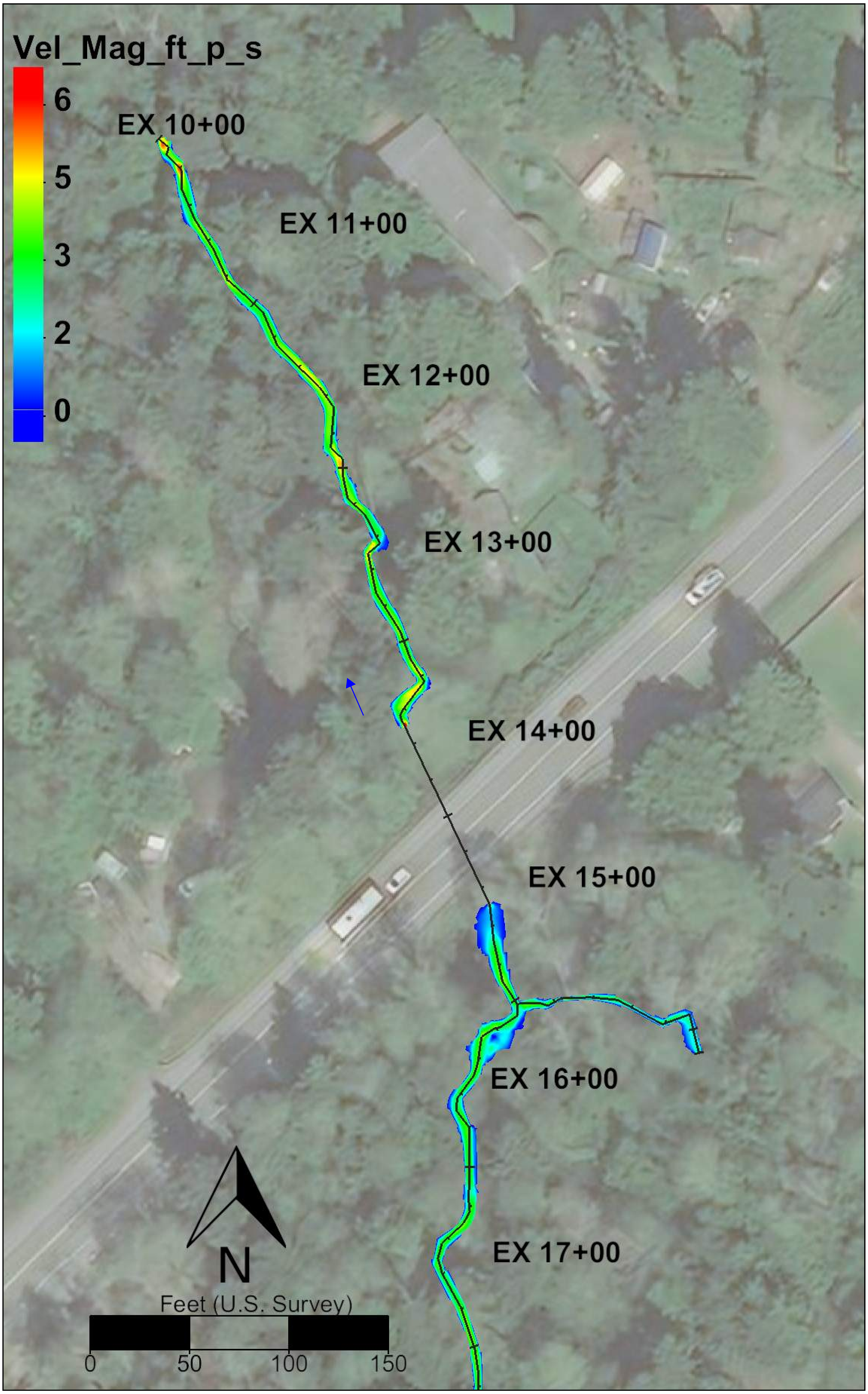
DRAFT



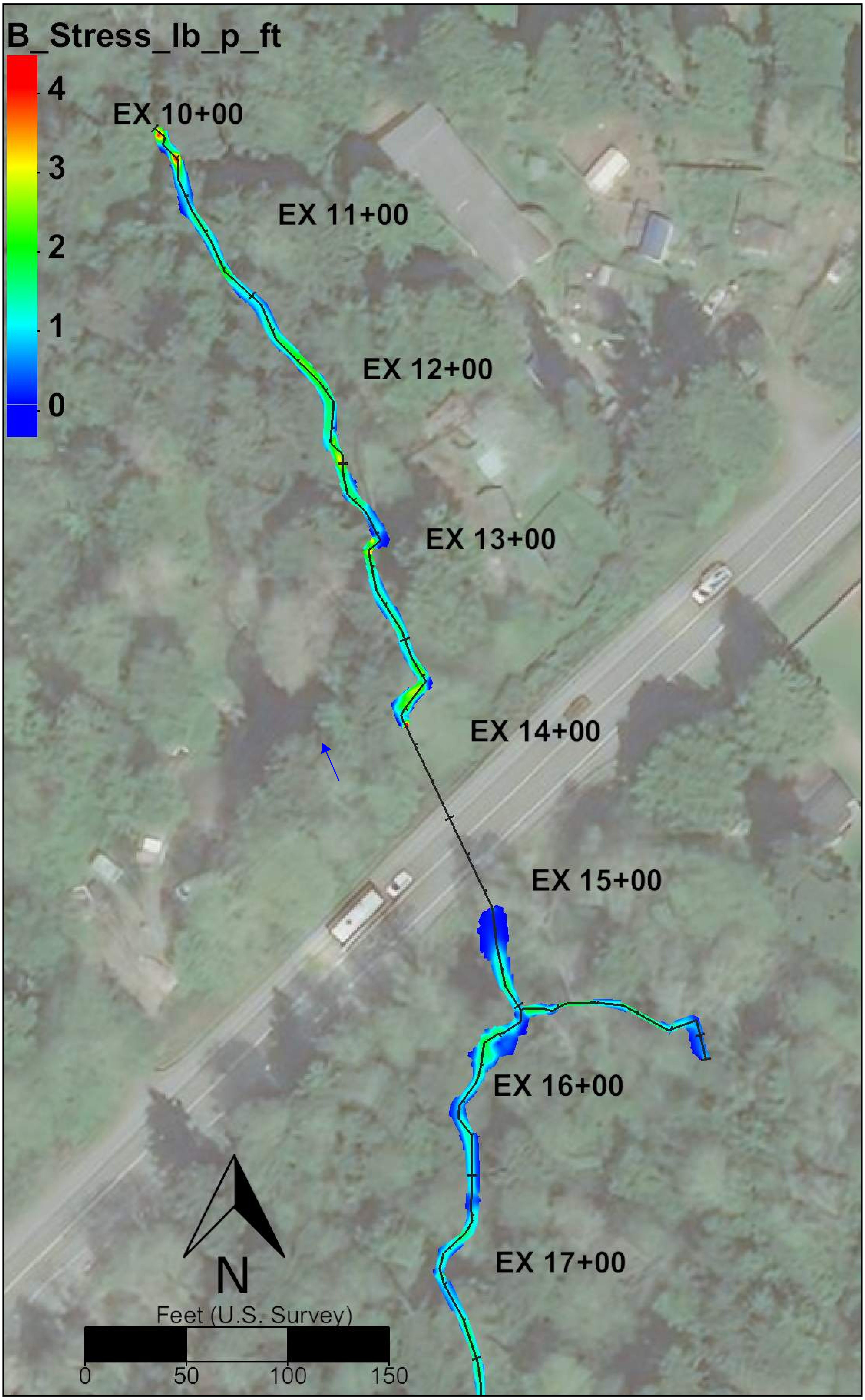
WATER SURFACE ELEVATION


Water_Depth_ft
2
1
1
0
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

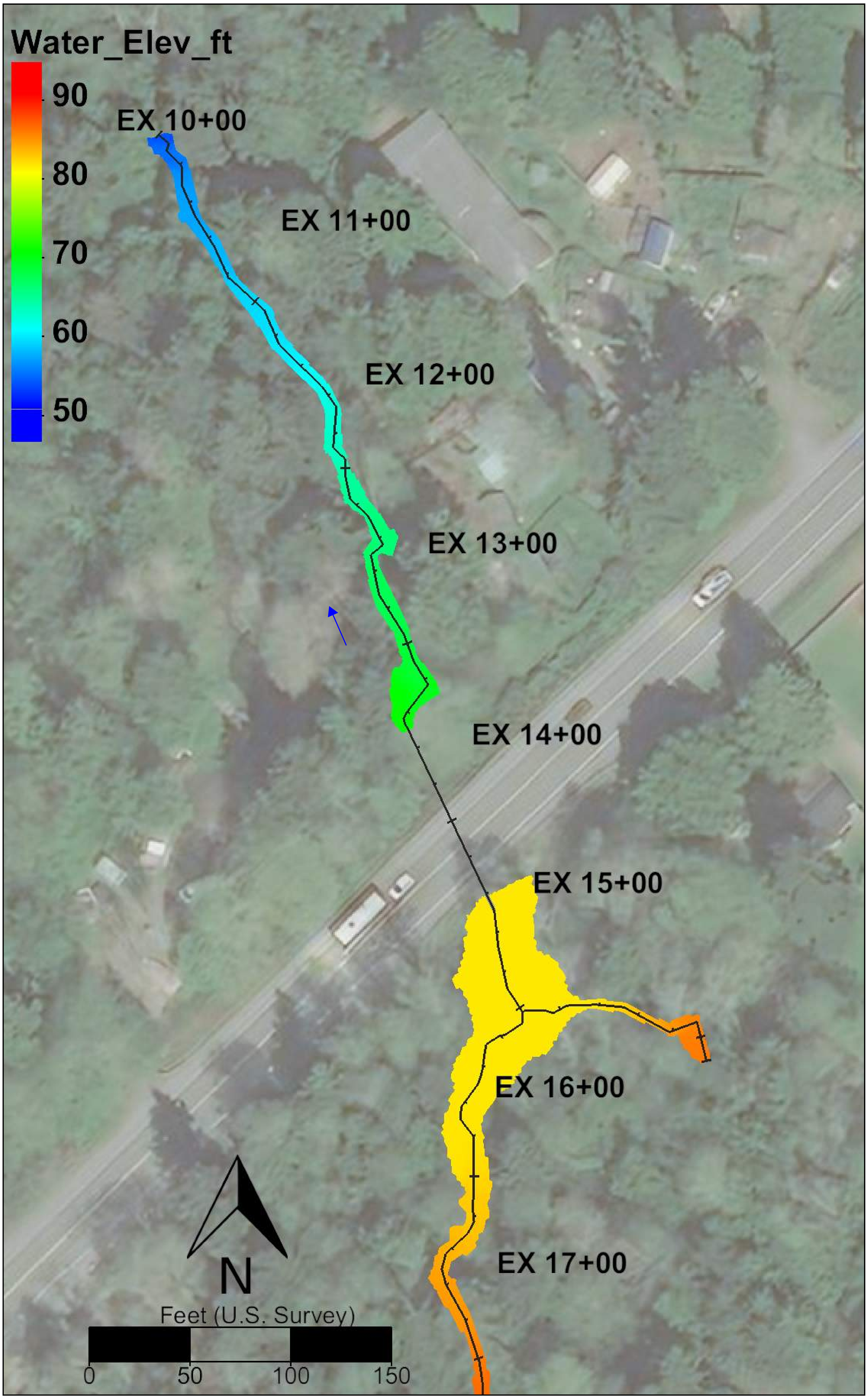
DEPTH


Vel_Mag_ft_p_s
6
5
3
2
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

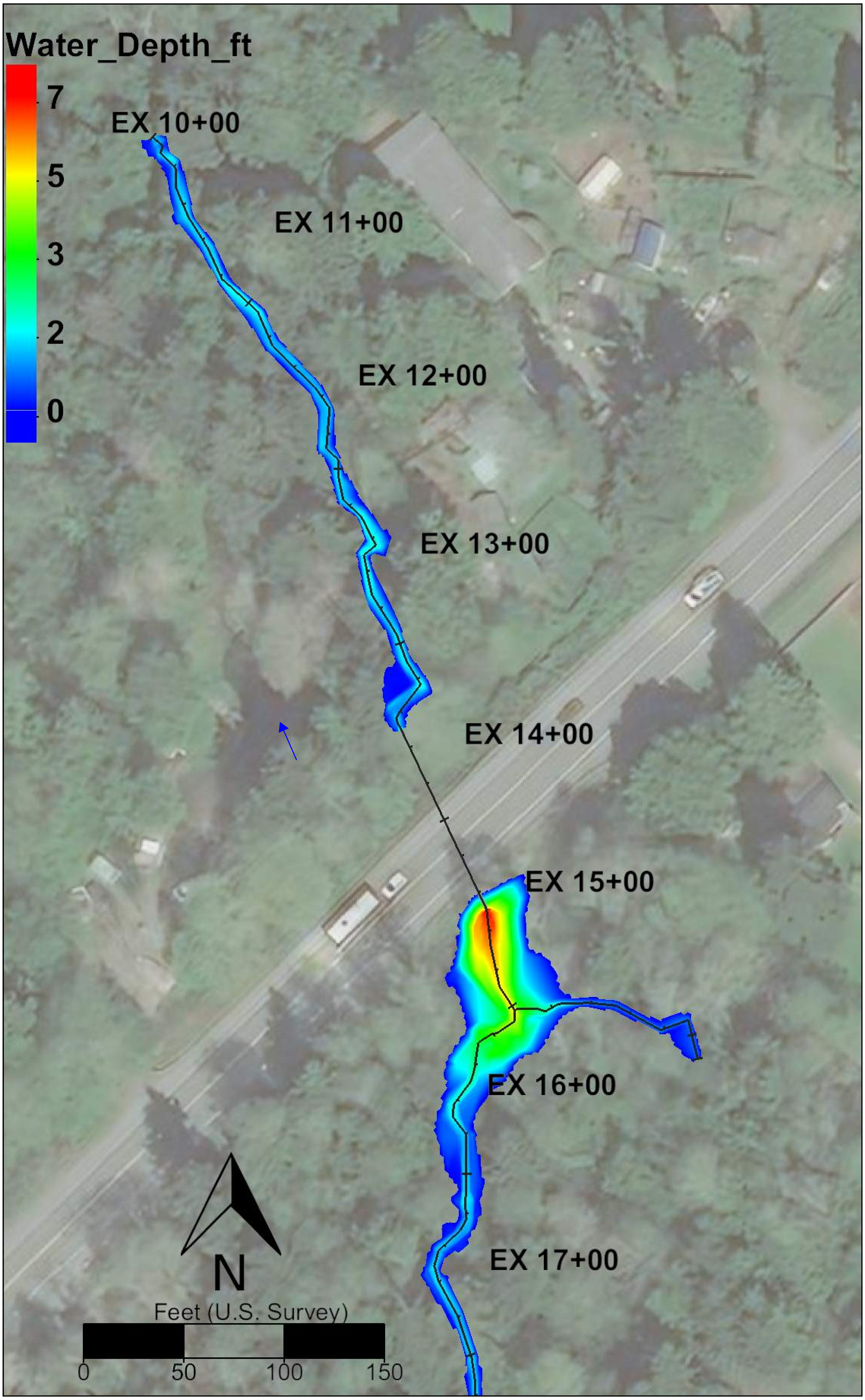
VELOCITY


B_Stress_lb_p_ft
4
3
2
1
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

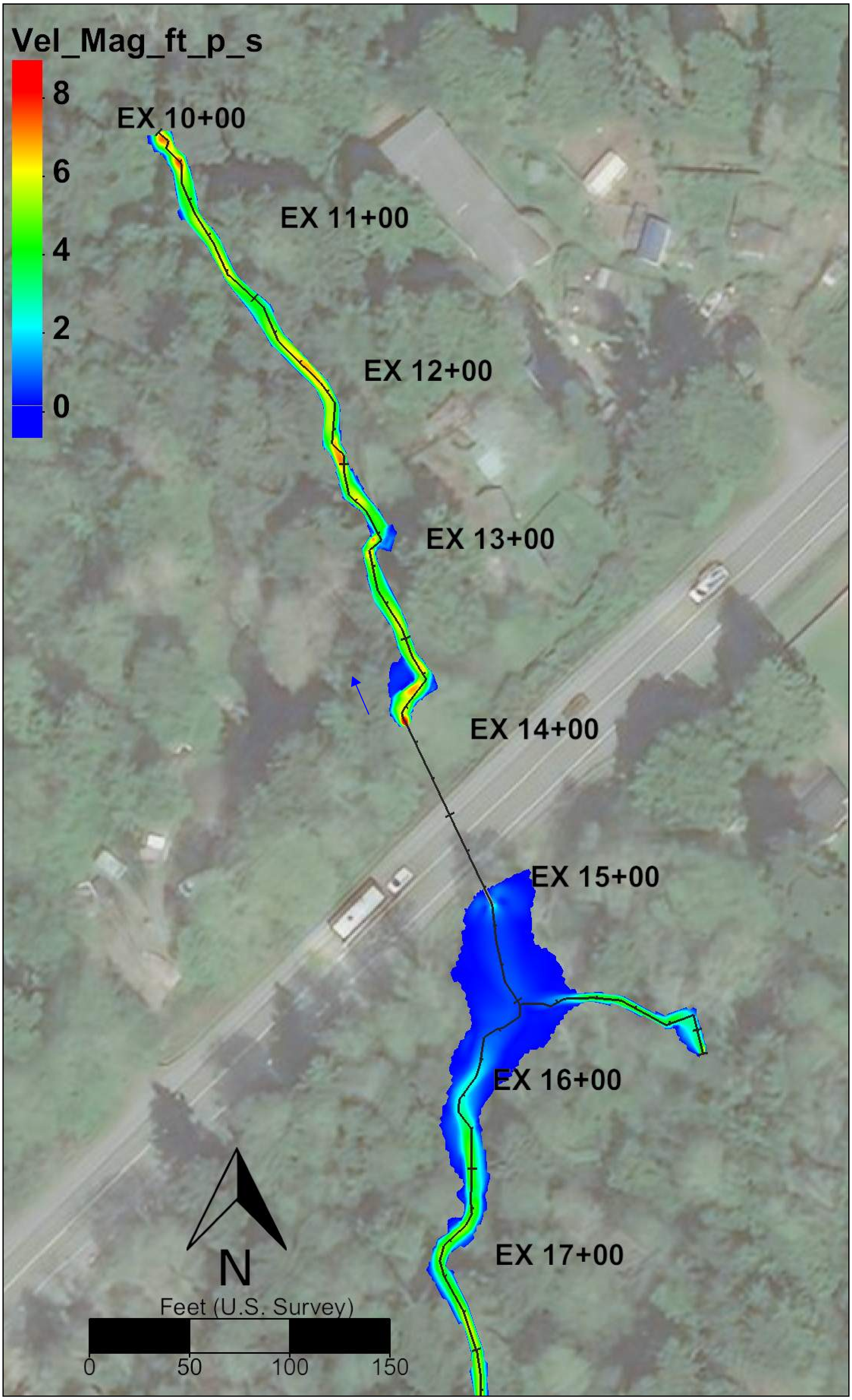
SHEAR



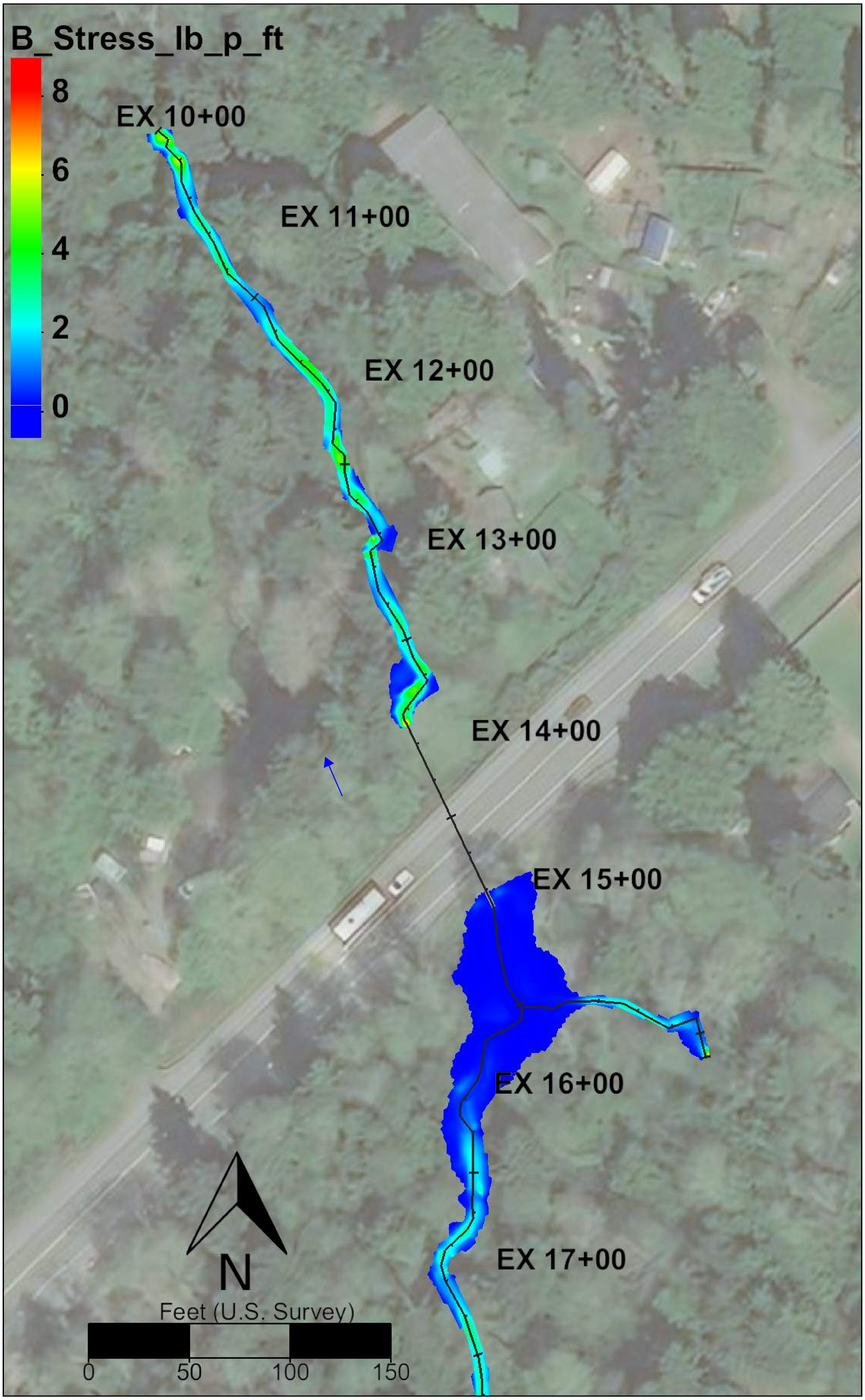
WATER SURFACE ELEVATION


Water_Depth_ft
7
5
3
2
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

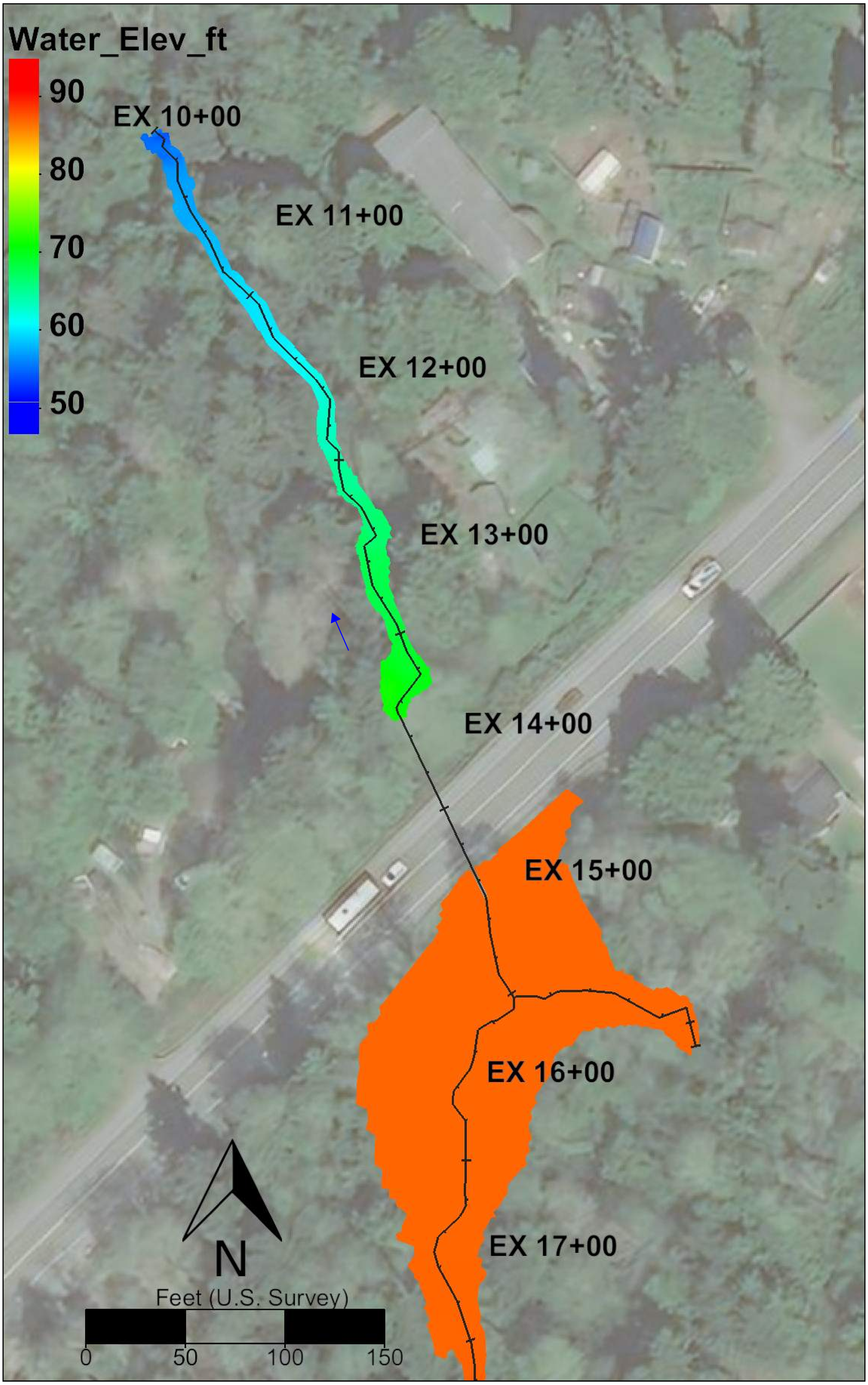
DEPTH


Vel_Mag_ft_p_s
8
6
4
2
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

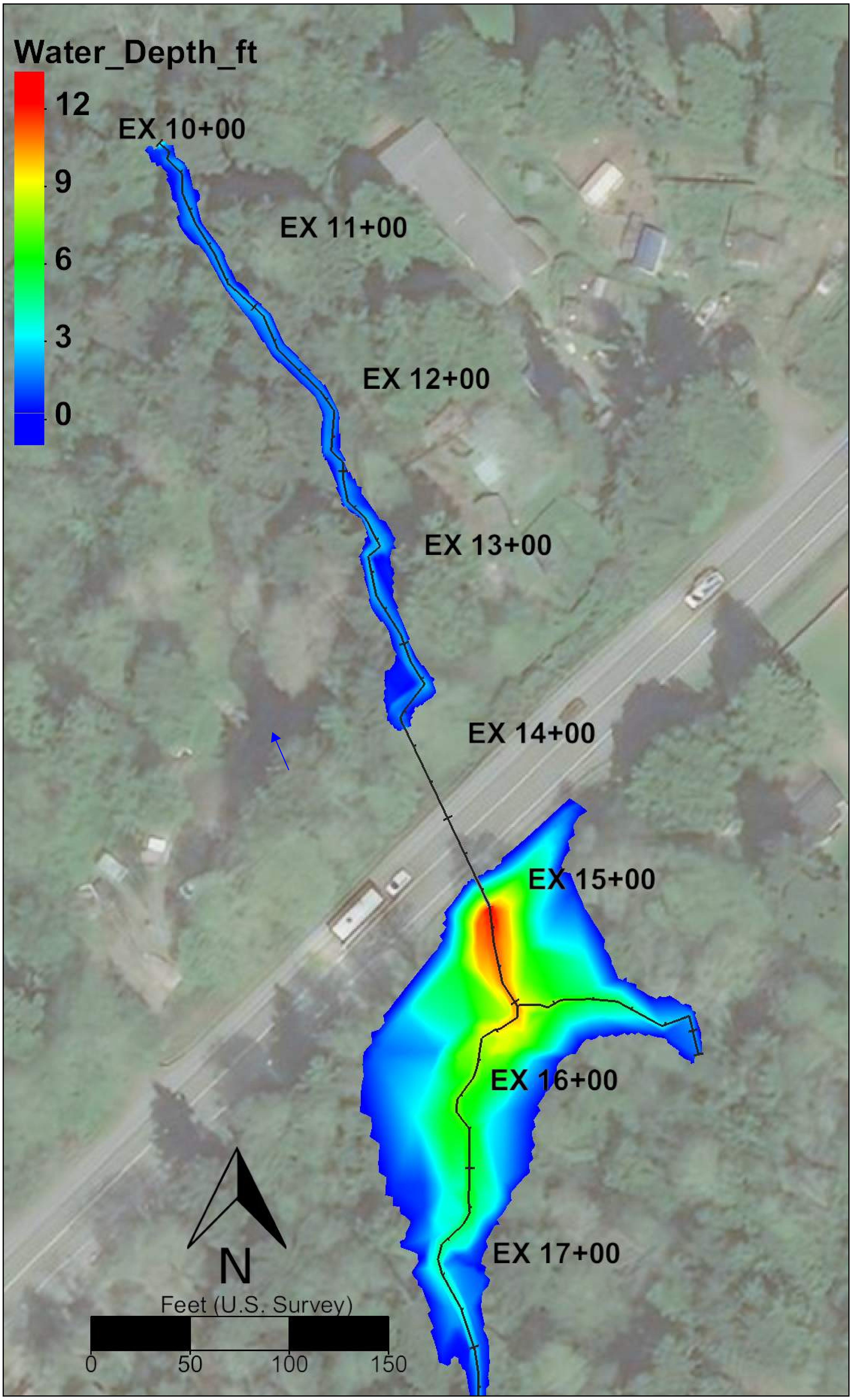
VELOCITY


B_Stress_lb_p_ft
8
6
4
2
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

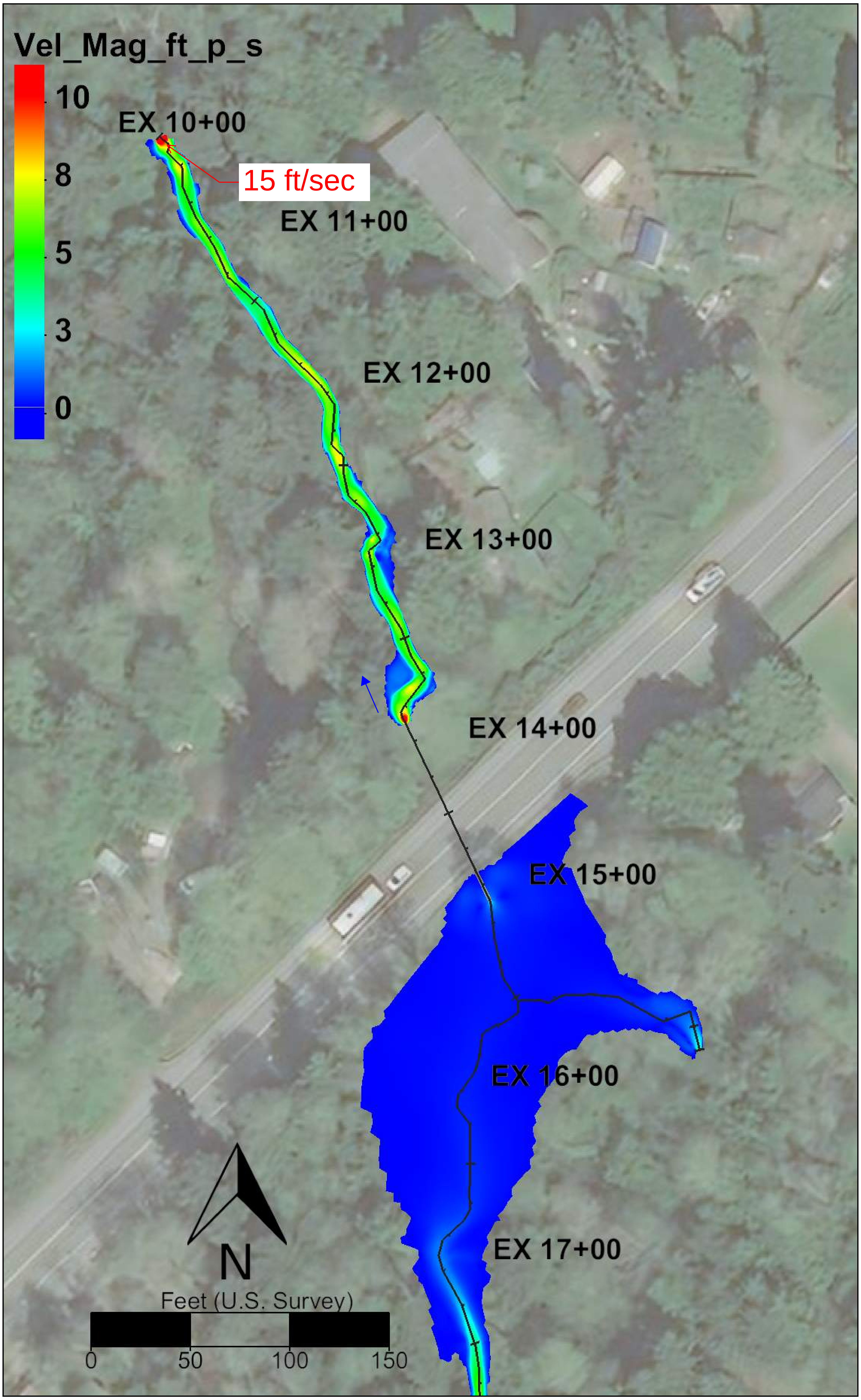
SHEAR



WATER SURFACE ELEVATION

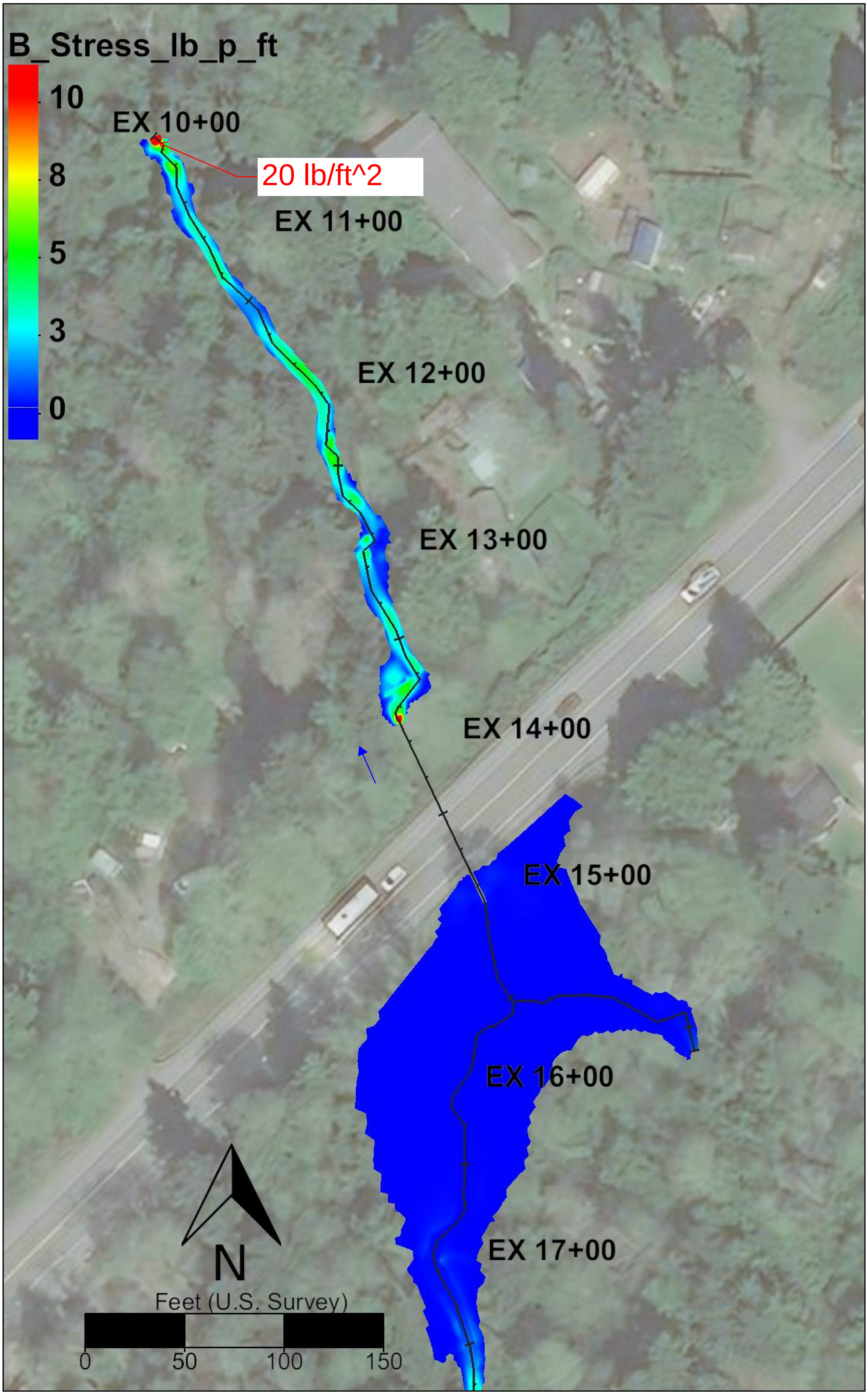

Water_Depth_ft
12
9
6
3
0
EX 10+00
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

DEPTH

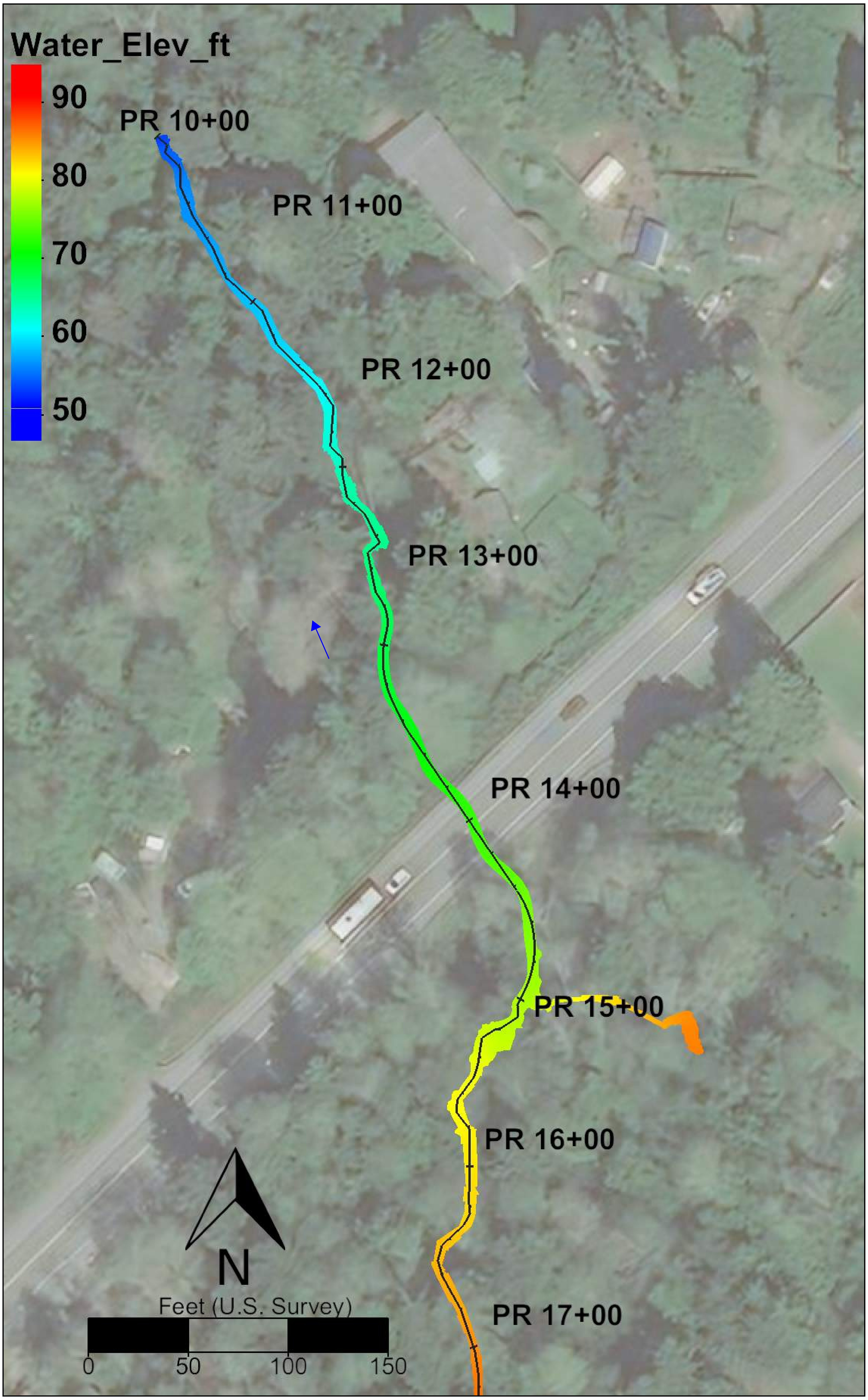


Vel_Mag_ft_p_s
10
8
5
3
0
EX 10+00
15 ft/sec
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

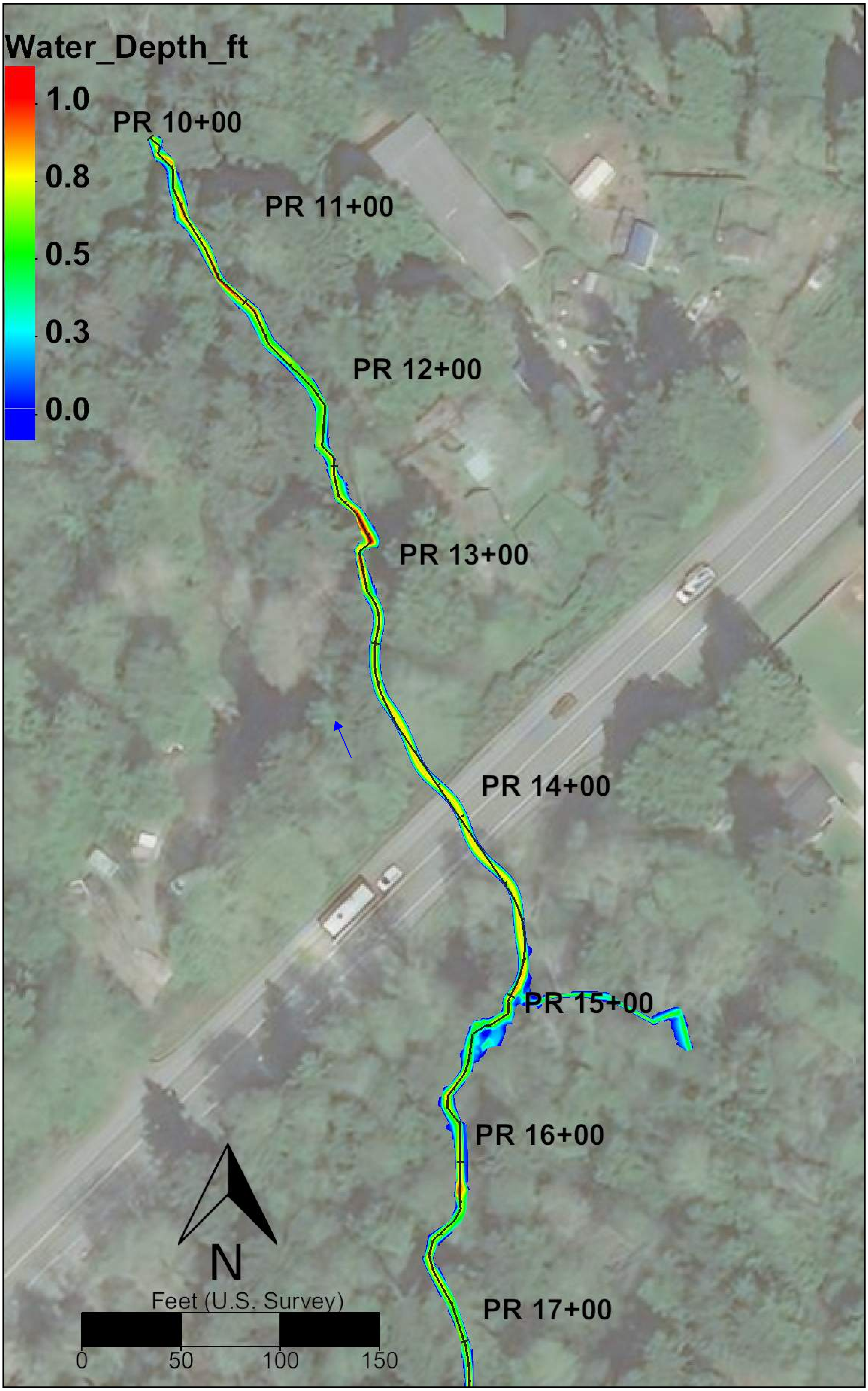
VELOCITY


B_Stress_lb_p_ft
10
8
5
3
0
EX 10+00
20 lb/ft^2
EX 11+00
EX 12+00
EX 13+00
EX 14+00
EX 15+00
EX 16+00
EX 17+00
N
Feet (U.S. Survey)
0
50
100
150

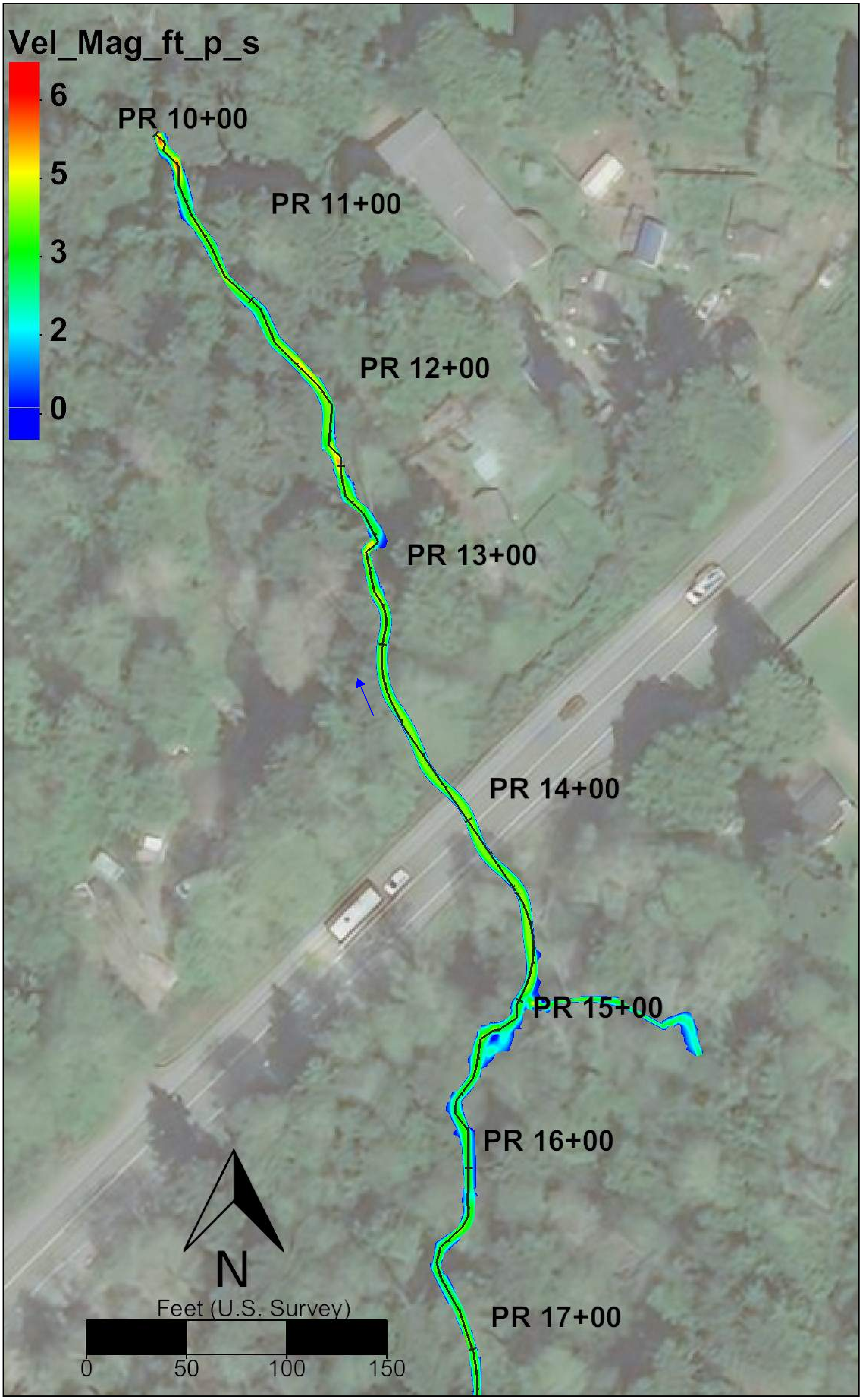
SHEAR



WATER SURFACE ELEVATION


Water_Depth_ft
1.0
0.8
0.5
0.3
0.0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

DEPTH

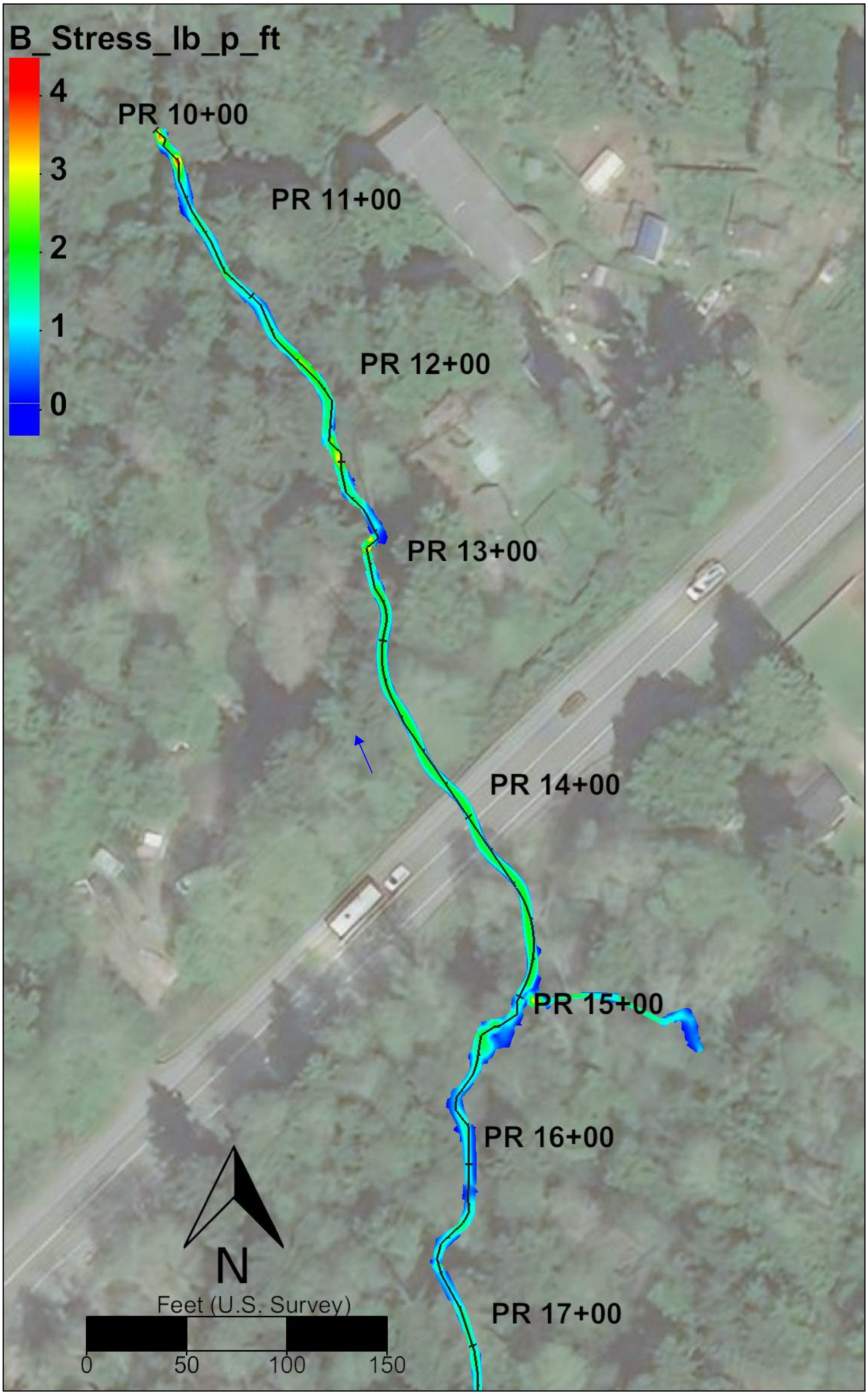


VELOCITY

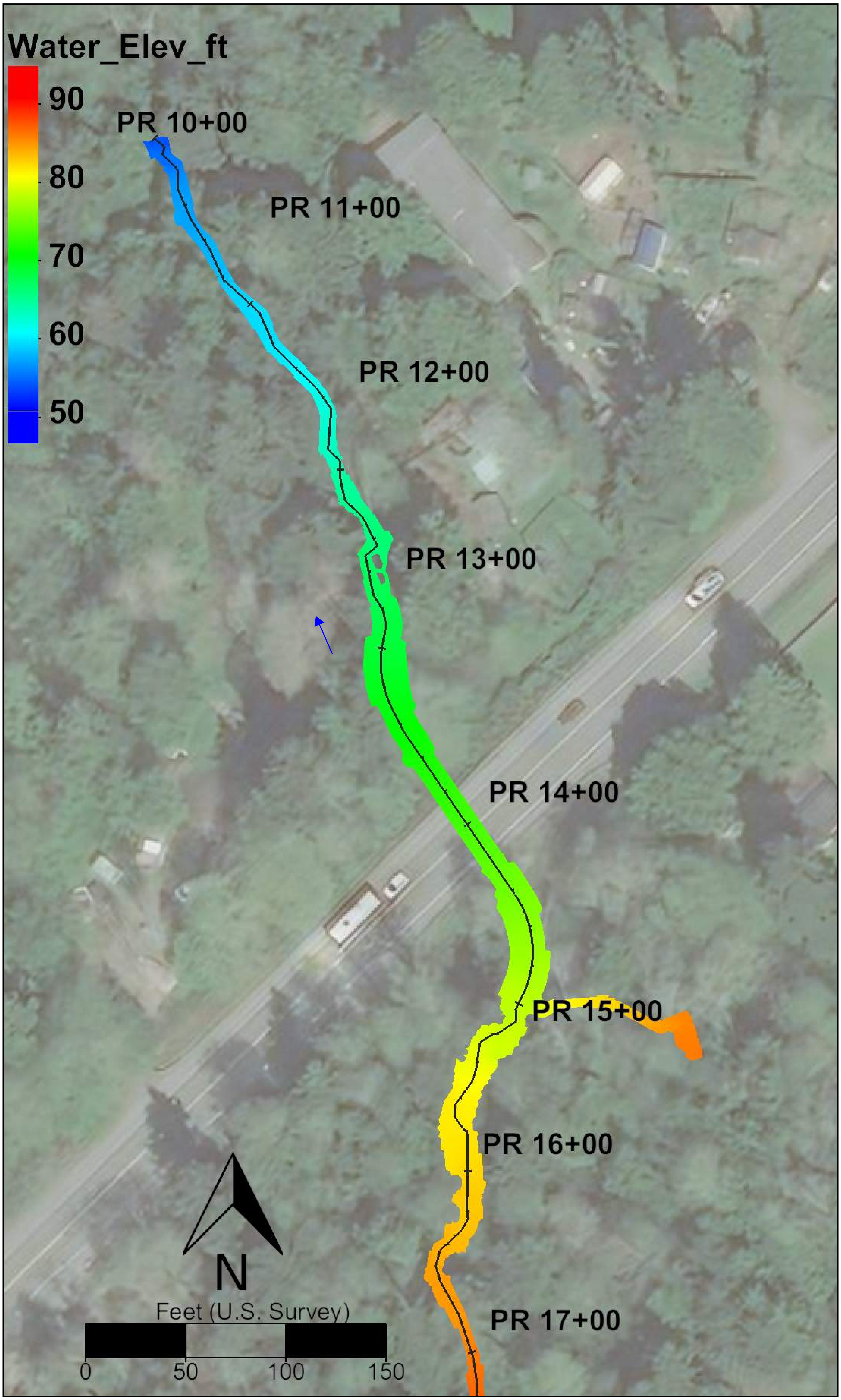
WSDOT OLYMPIC REGION GEC

PROPOSED CONDITION 2-YEAR EVENT

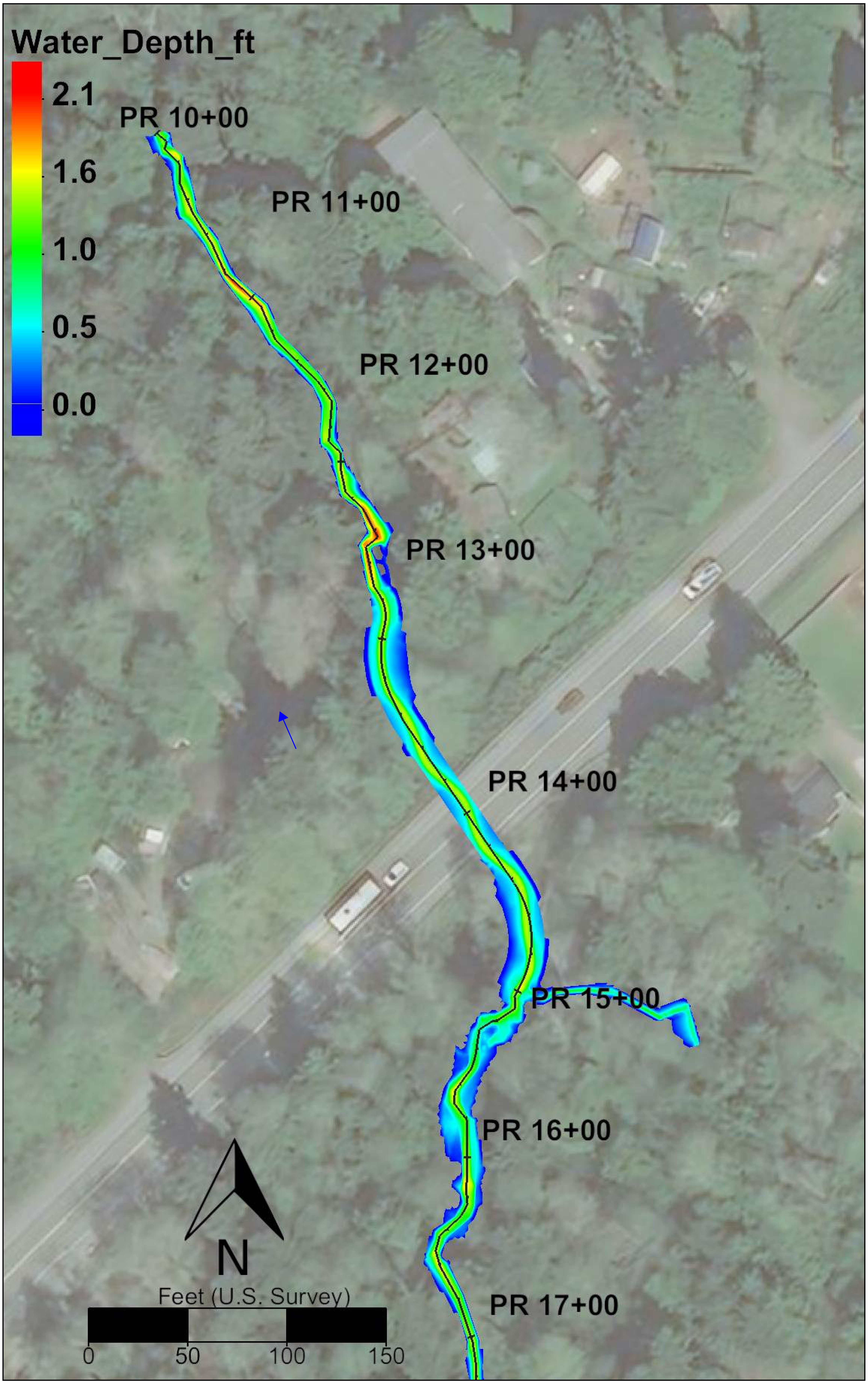
SR 3 MP 58.21 UNT to Hood Canal
WDFW ID: 991240


B_Stress_lb_p_ft
4
3
2
1
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

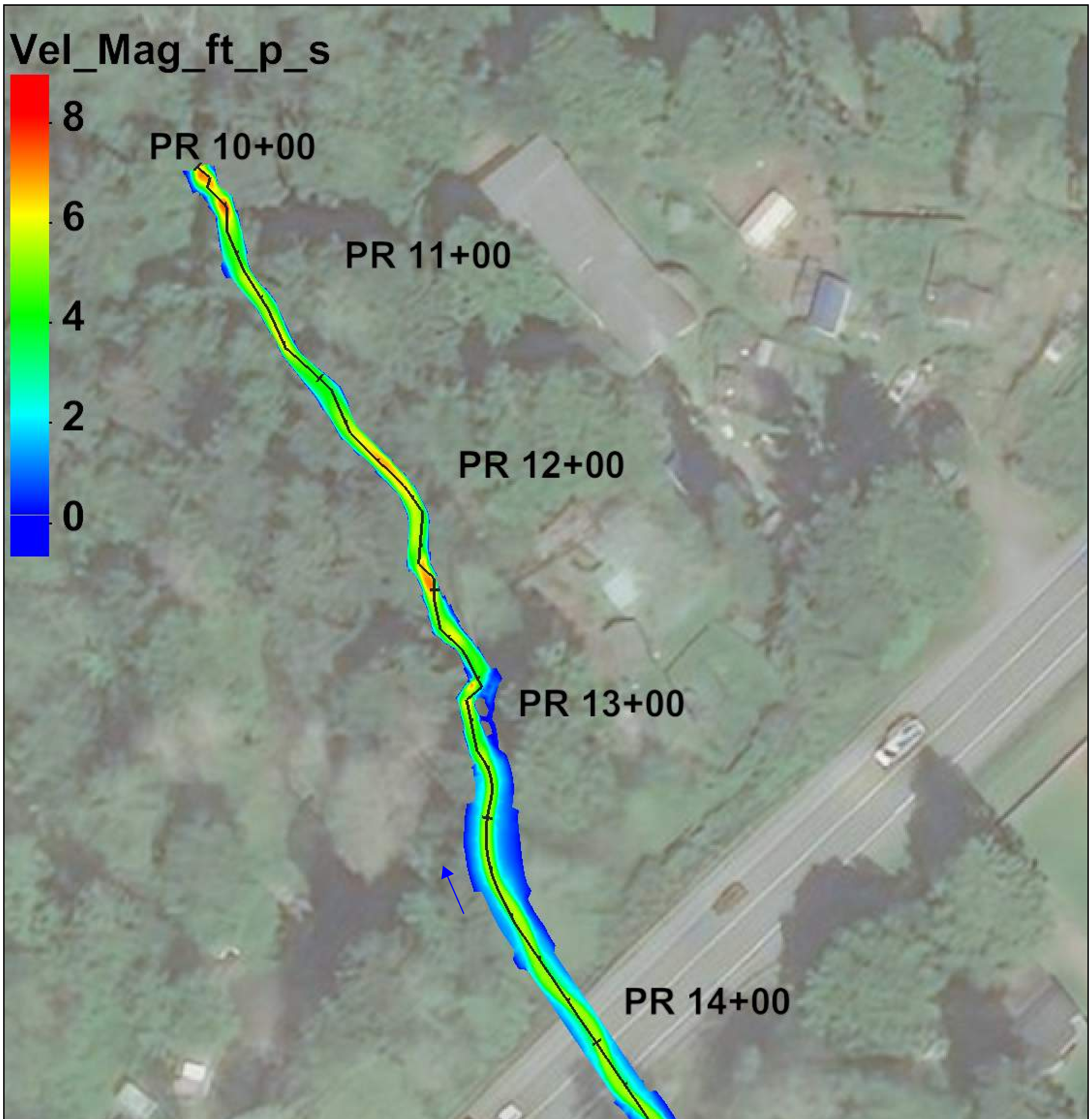
SHEAR



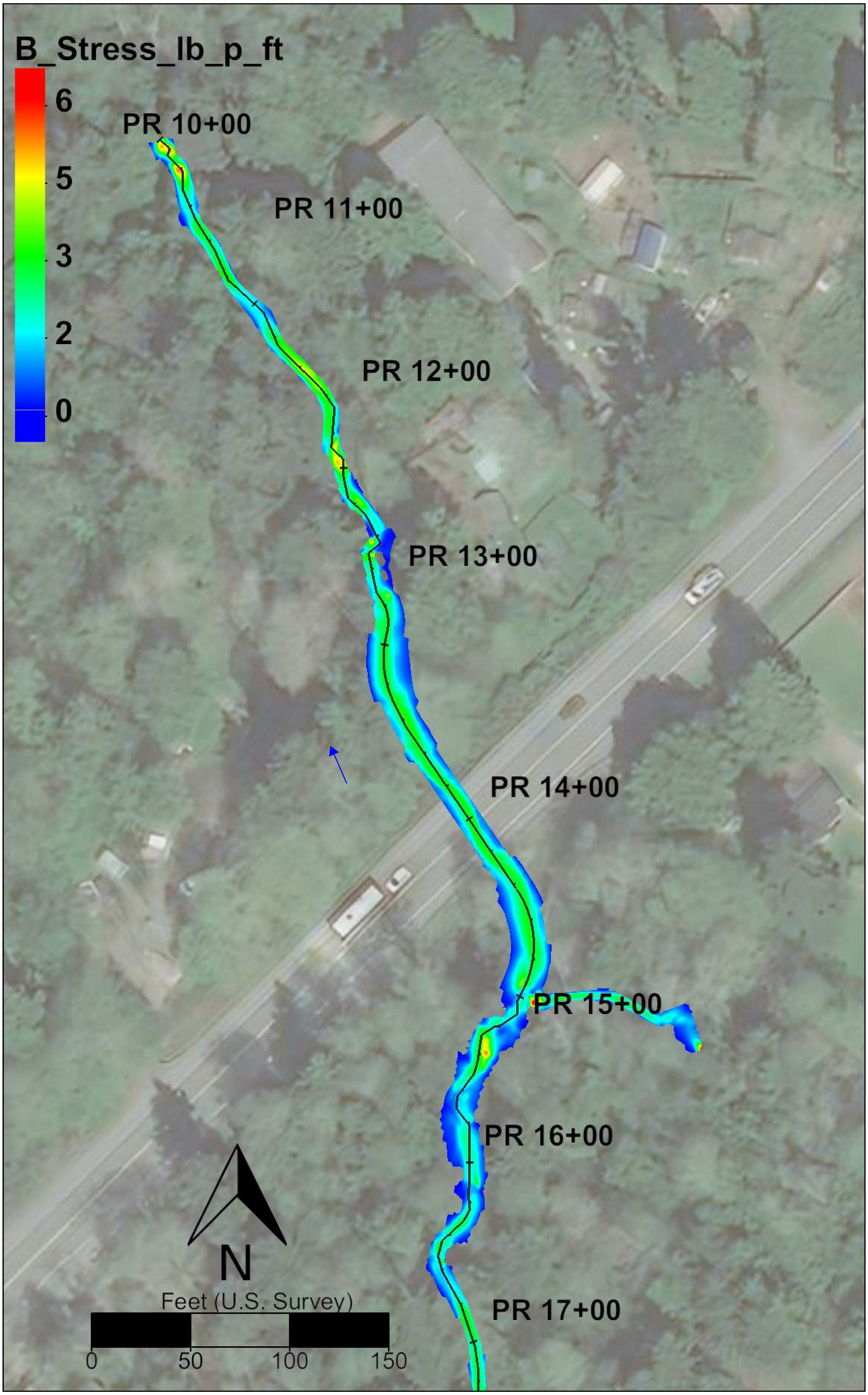
WATER SURFACE ELEVATION


Water_Depth_ft
2.1
1.6
1.0
0.5
0.0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

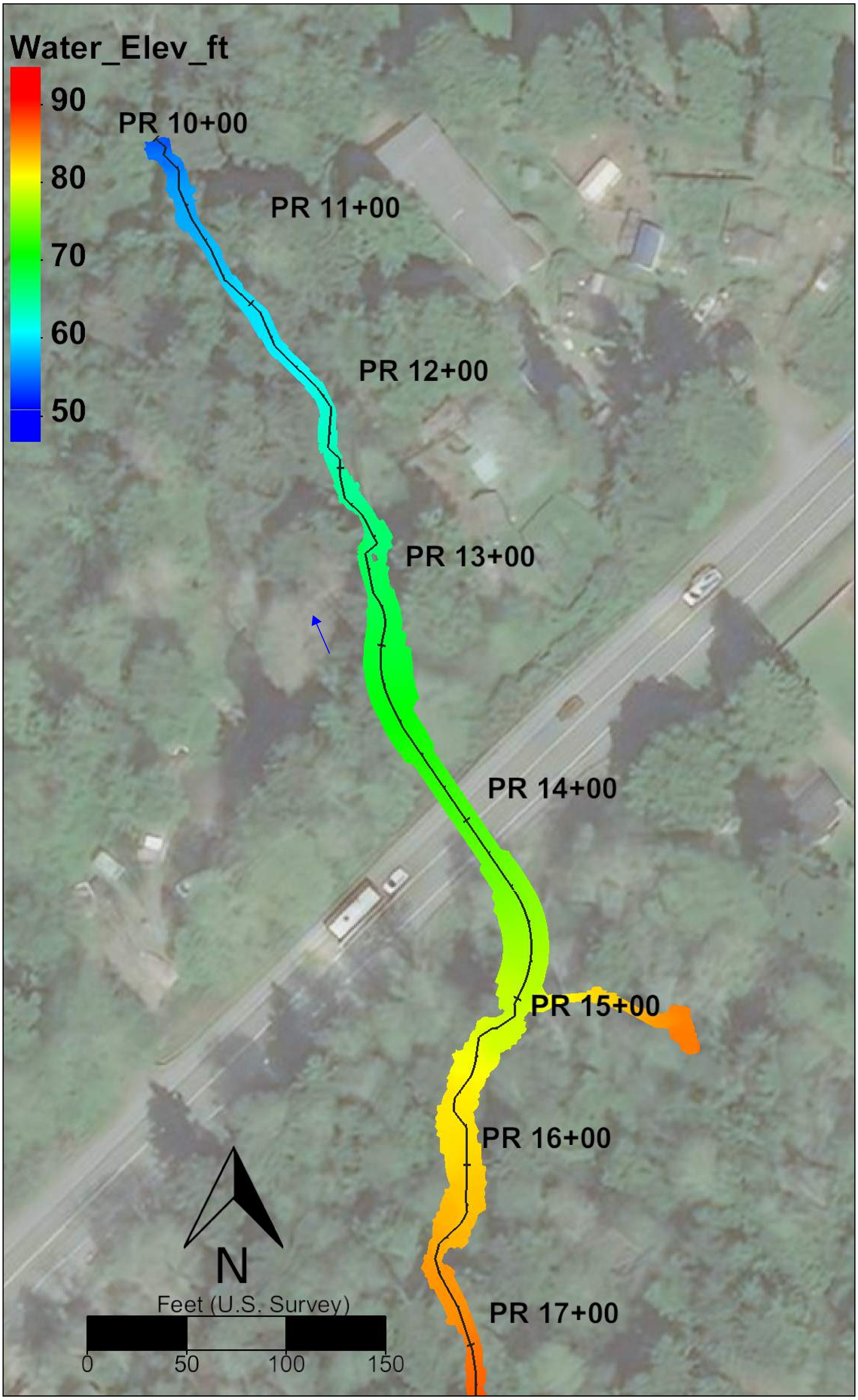
DEPTH


Vel_Mag_ft_p_s
8
6
4
2
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

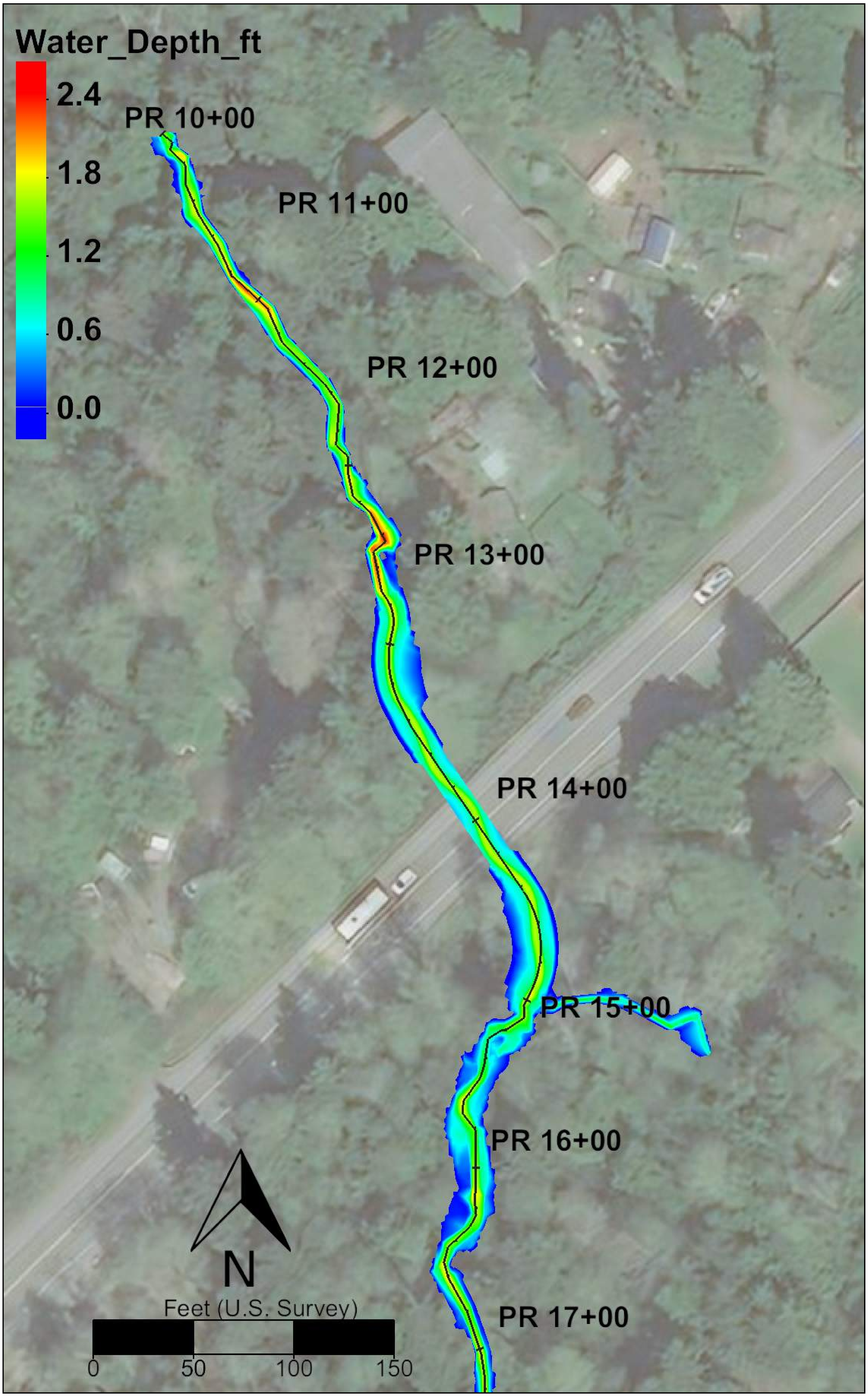
VELOCITY


B_Stress_lb_p_ft
6
5
3
2
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

SHEAR

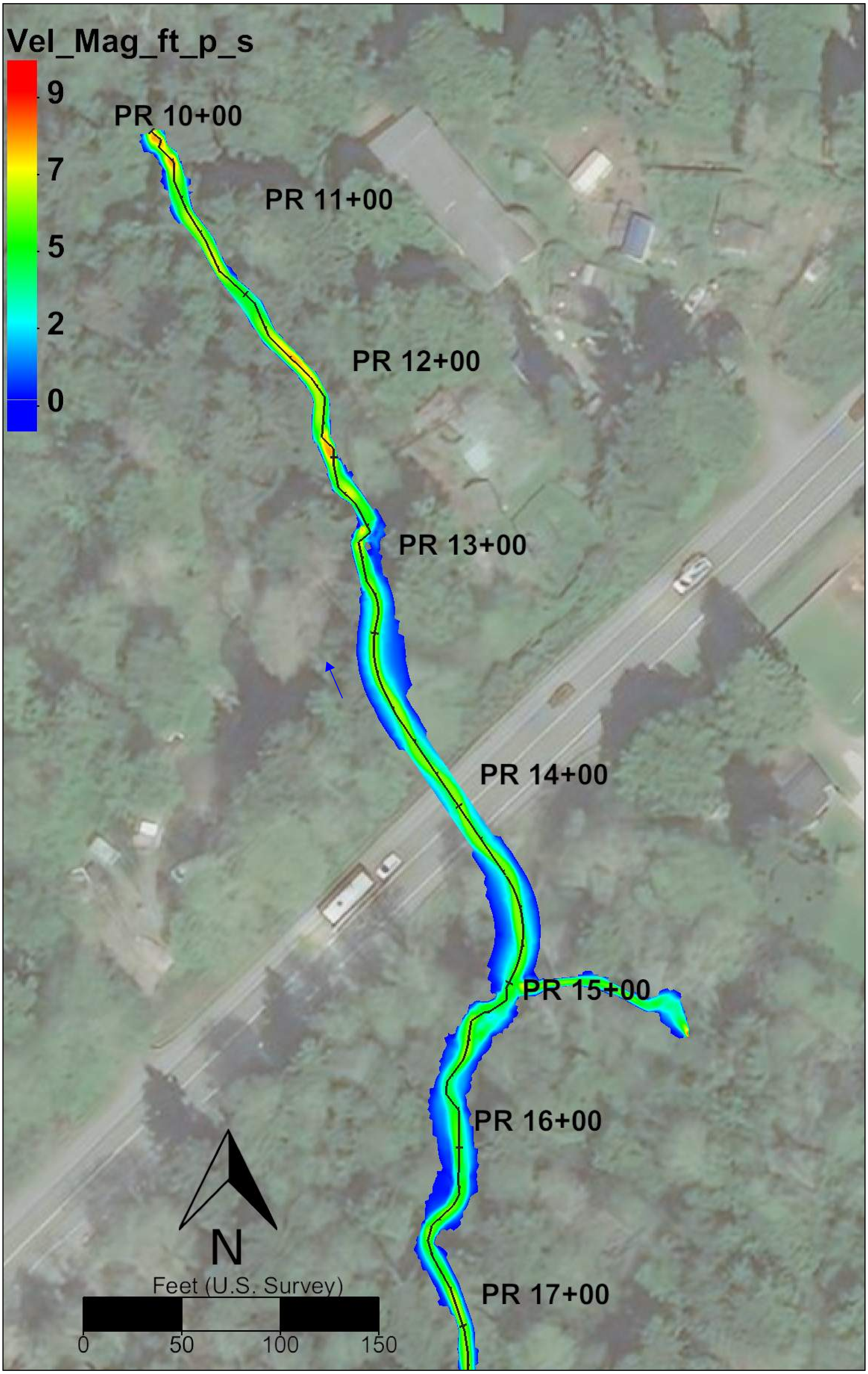


WATER SURFACE ELEVATION

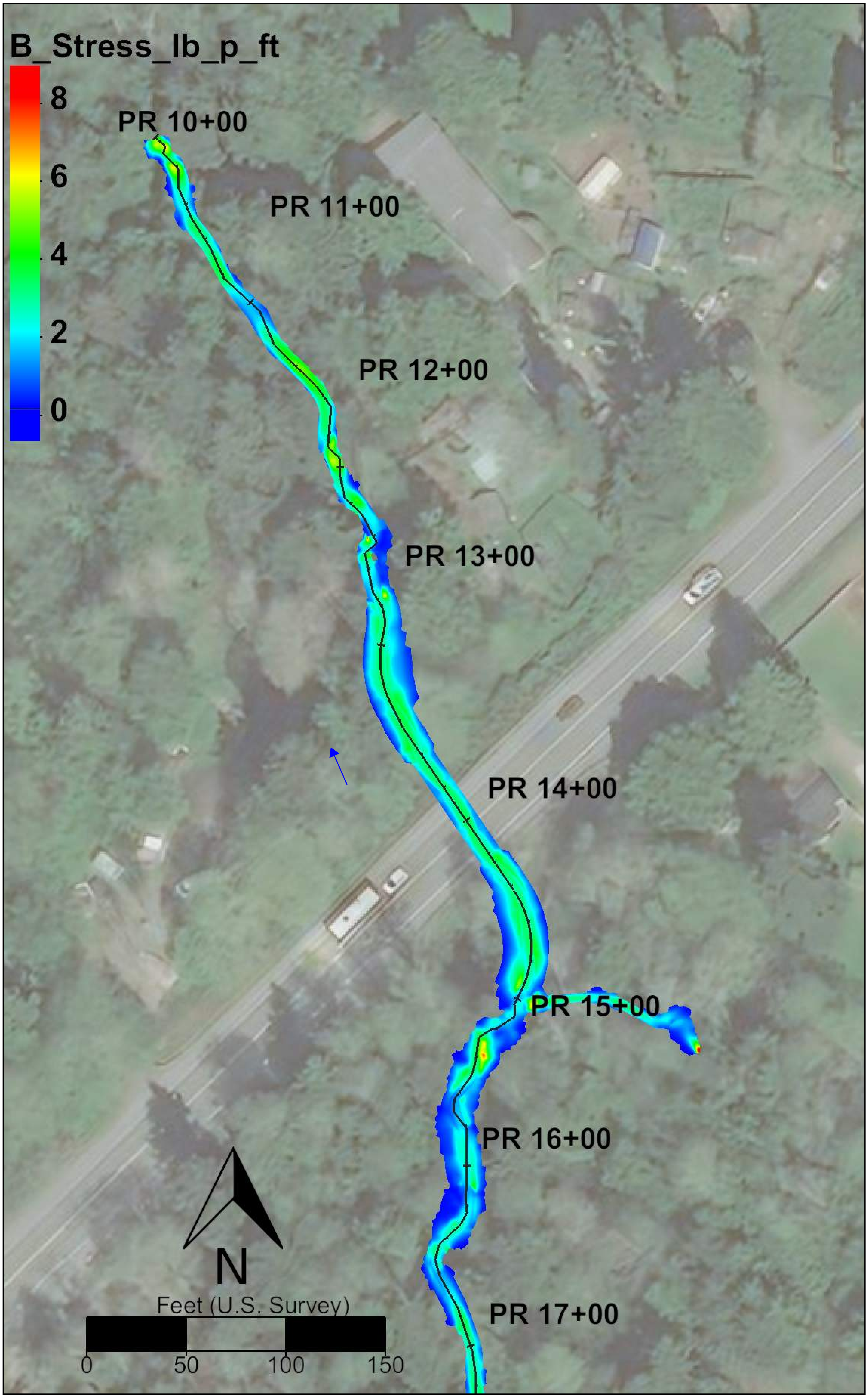


Water_Depth_ft
2.4
1.8
1.2
0.6
0.0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

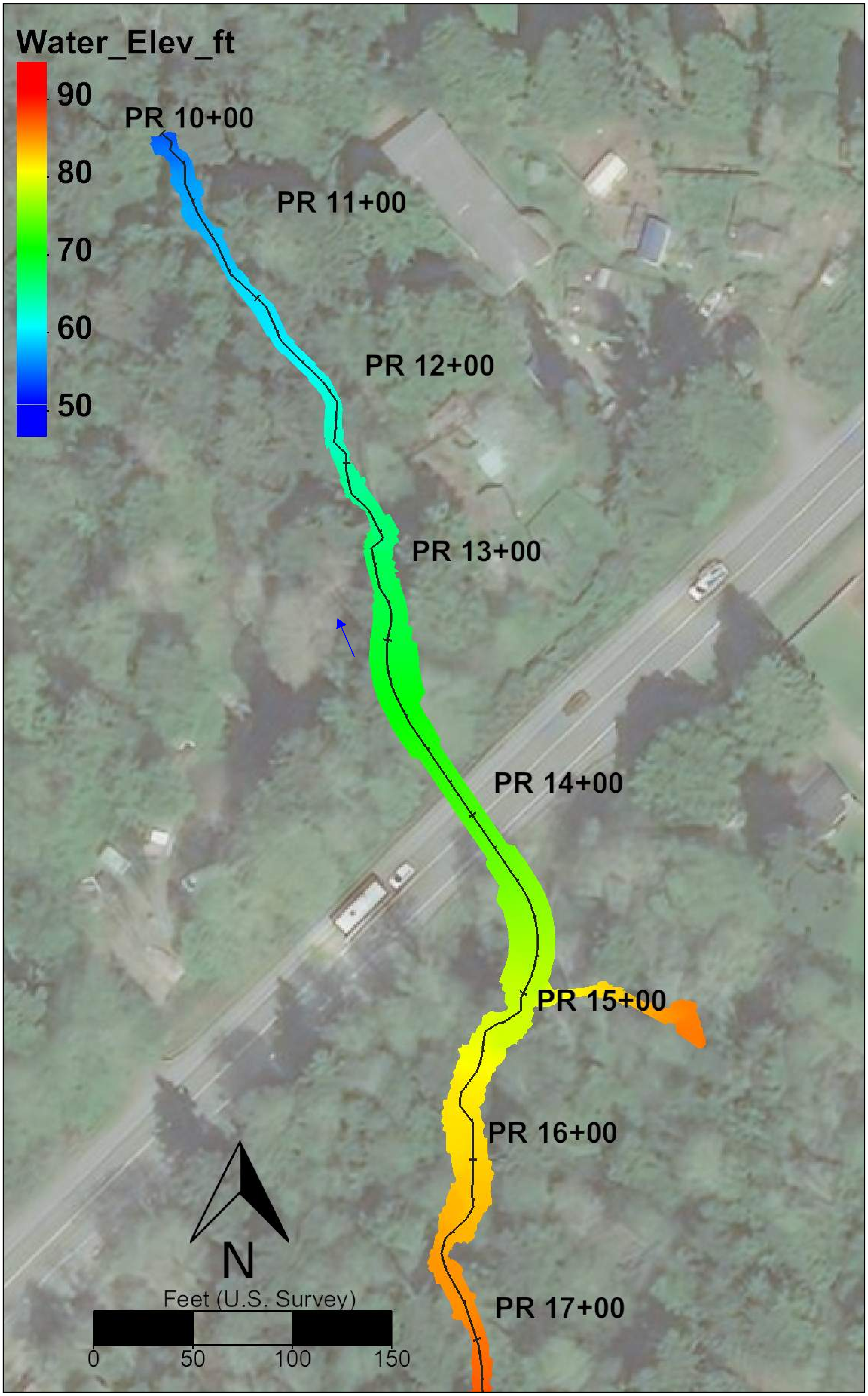
DEPTH


Vel_Mag_ft_p_s
9
7
5
2
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

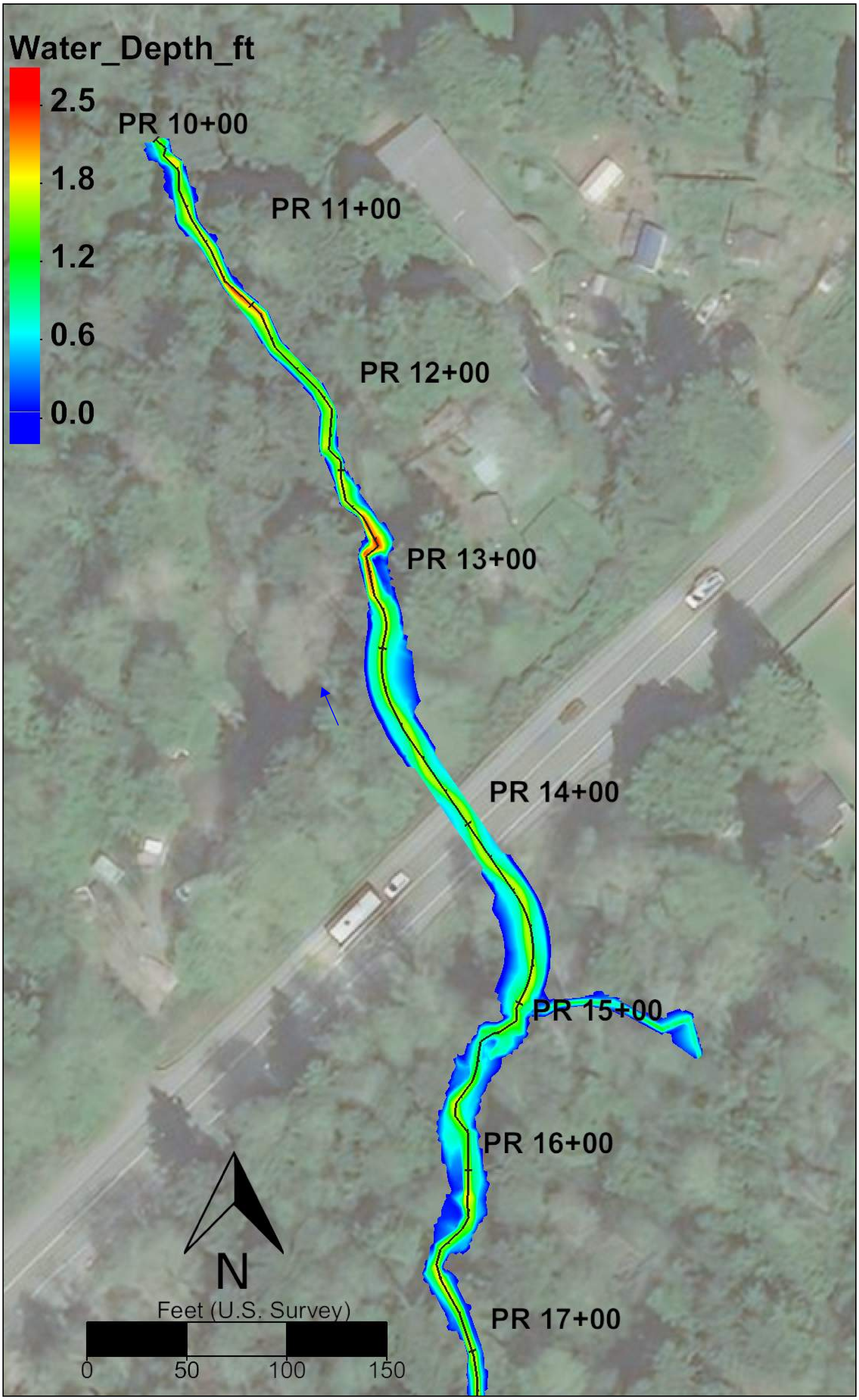
VELOCITY


B_Stress_lb_p_ft
8
6
4
2
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

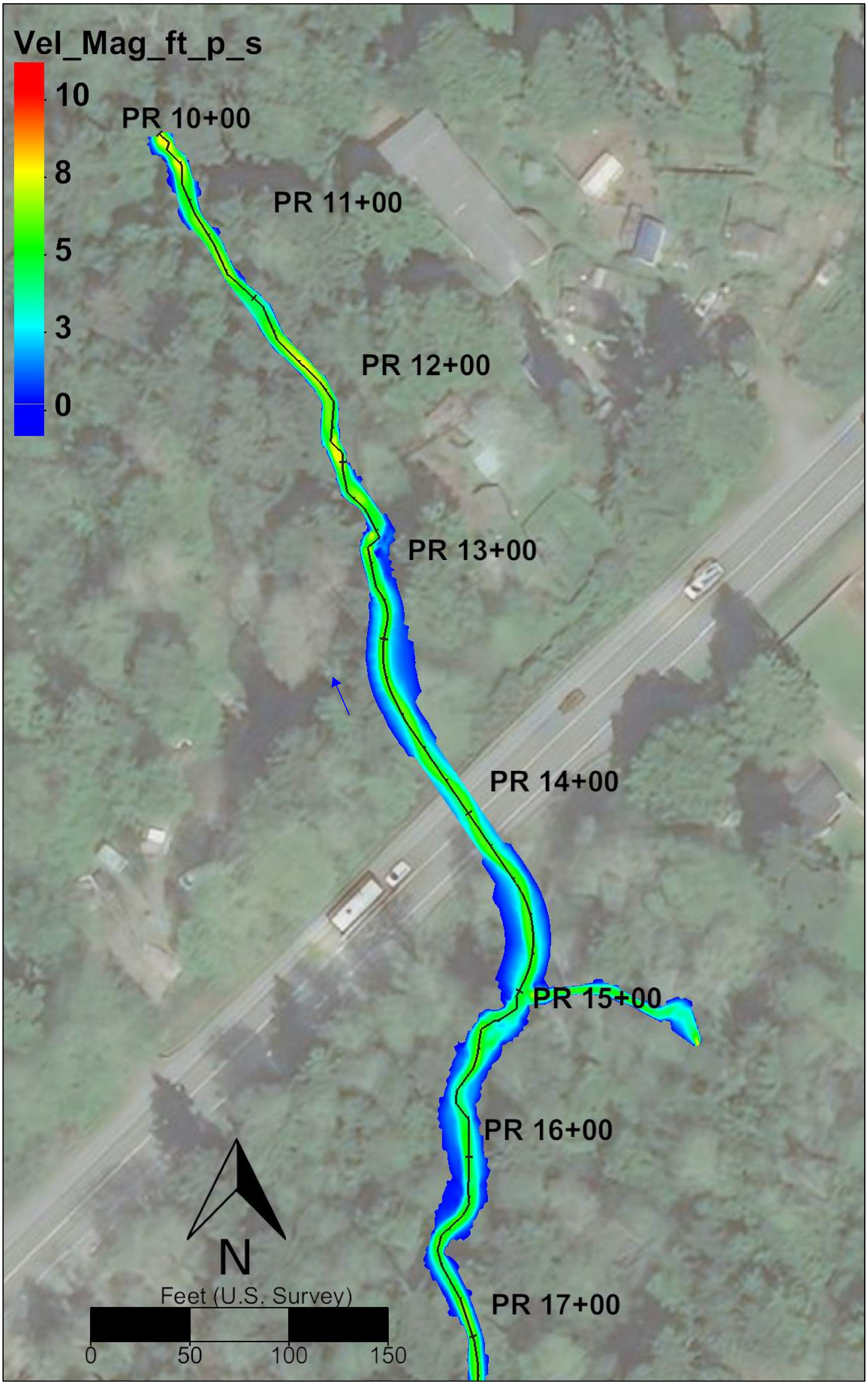
SHEAR



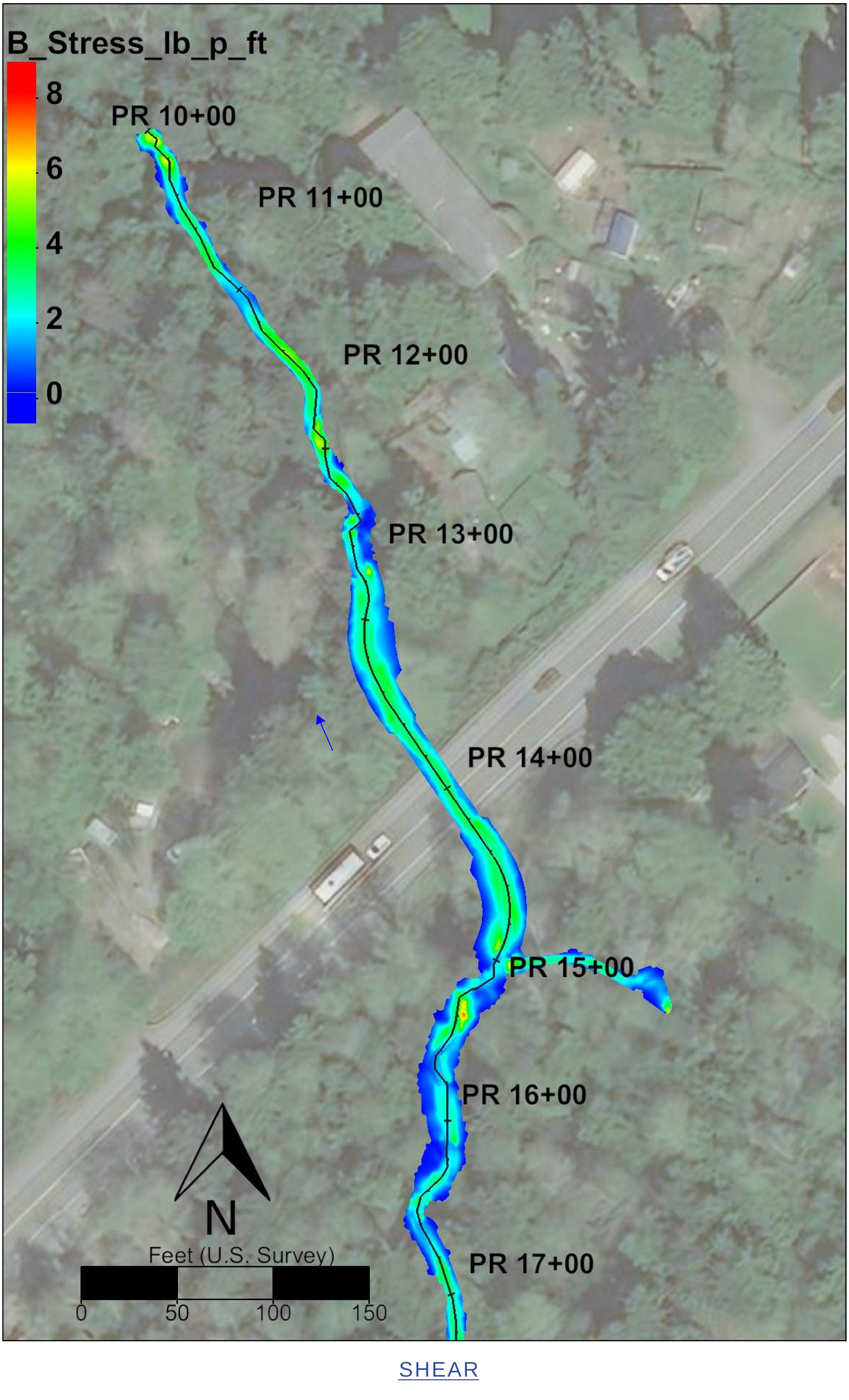
WATER SURFACE ELEVATION


Water_Depth_ft
2.5
1.8
1.2
0.6
0.0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

DEPTH


Vel_Mag_ft_p_s
10
8
5
3
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

VELOCITY


B_Stress_lb_p_ft
8
6
4
2
0
PR 10+00
PR 11+00
PR 12+00
PR 13+00
PR 14+00
PR 15+00
PR 16+00
PR 17+00
N
Feet (U.S. Survey)
0
50
100
150

SHEAR

Appendix I: SRH-2D Model Stability and Continuity

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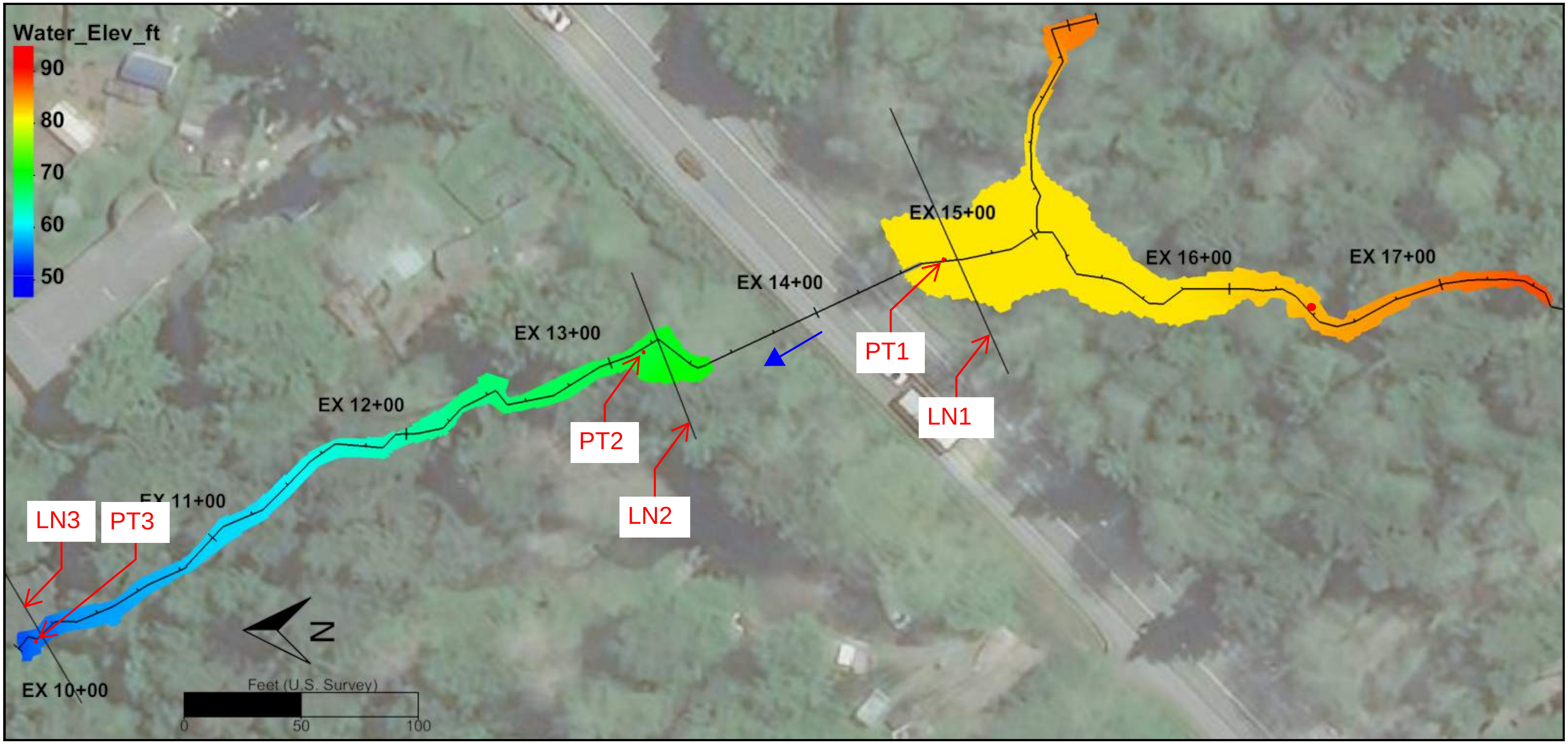
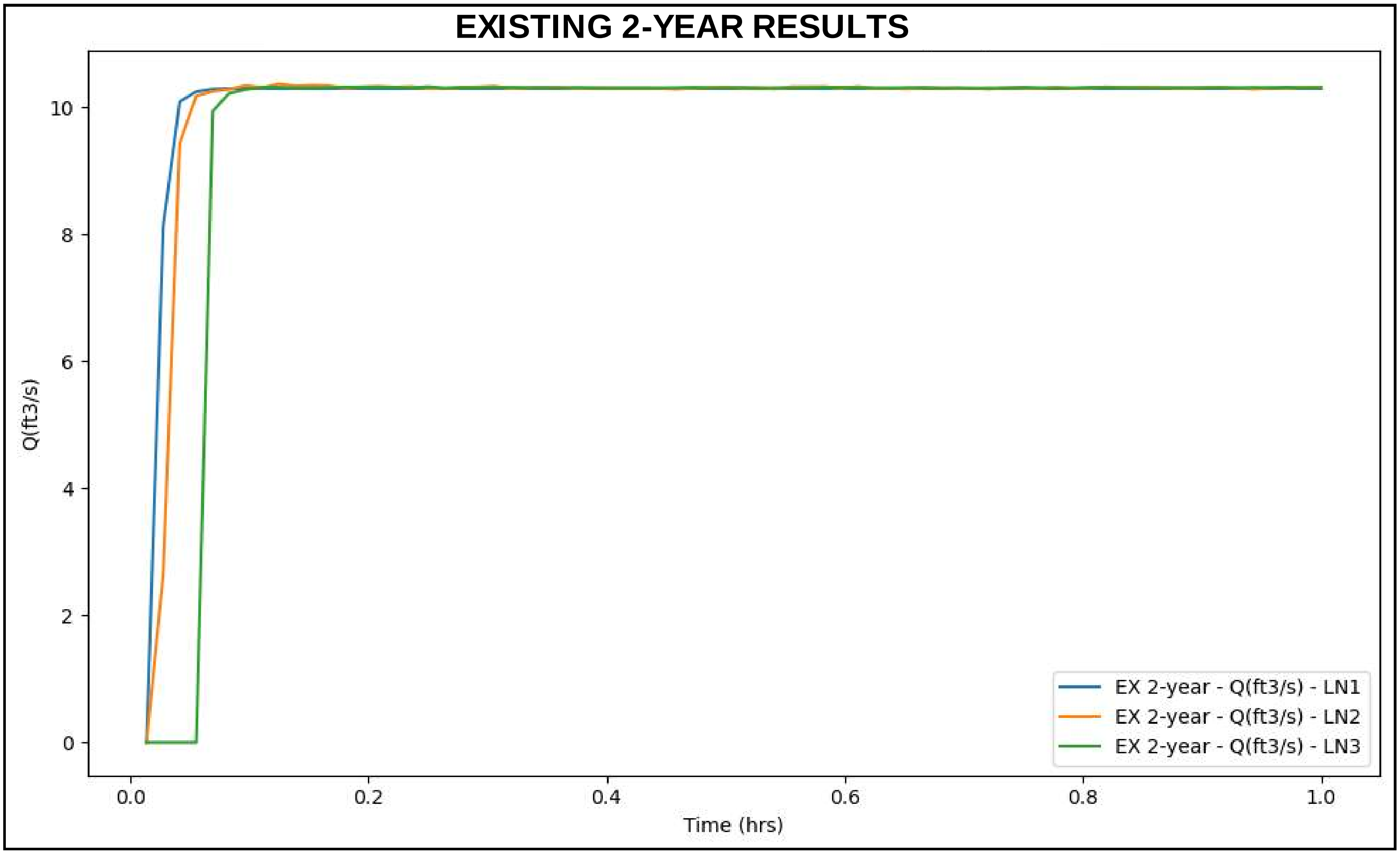
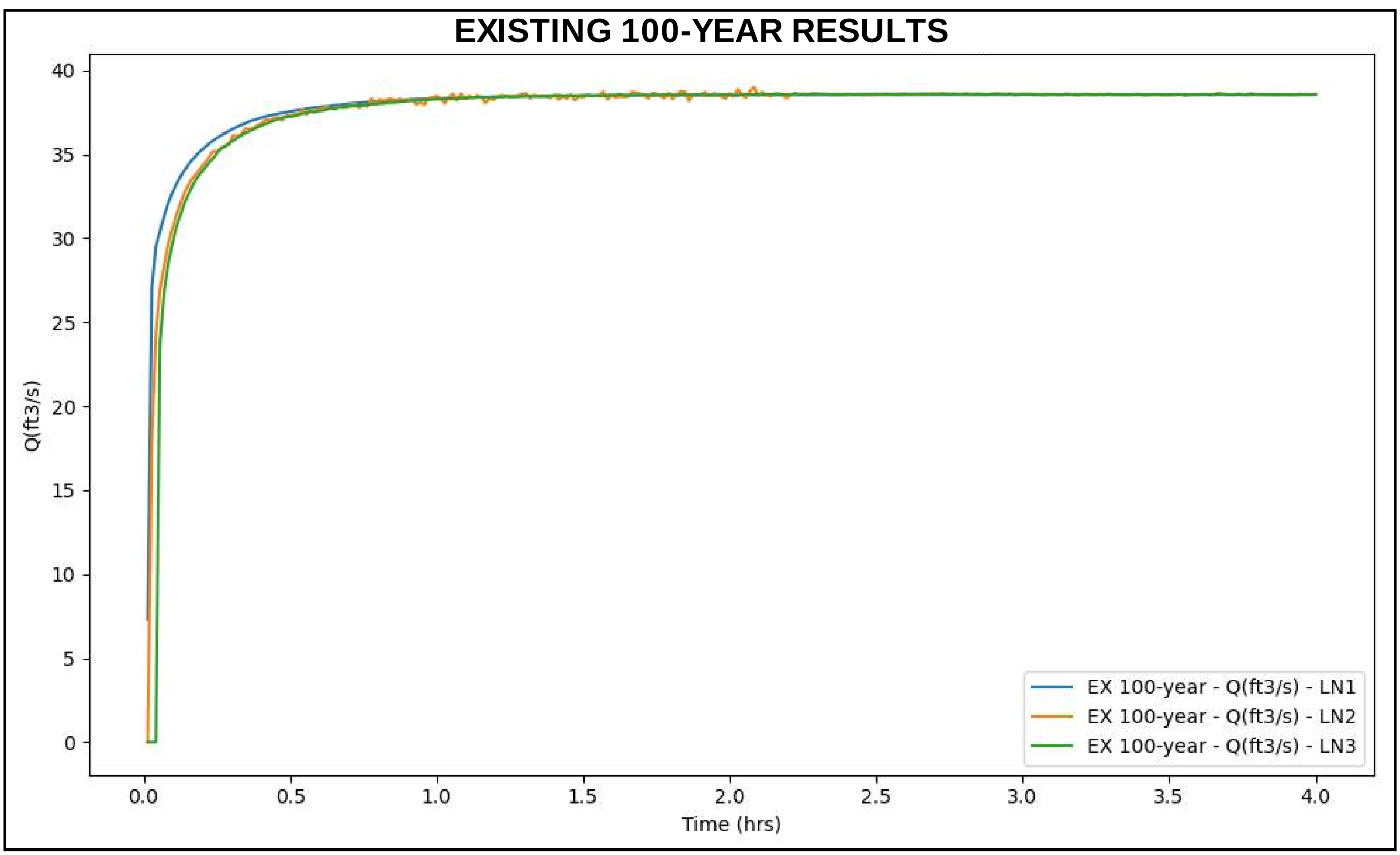
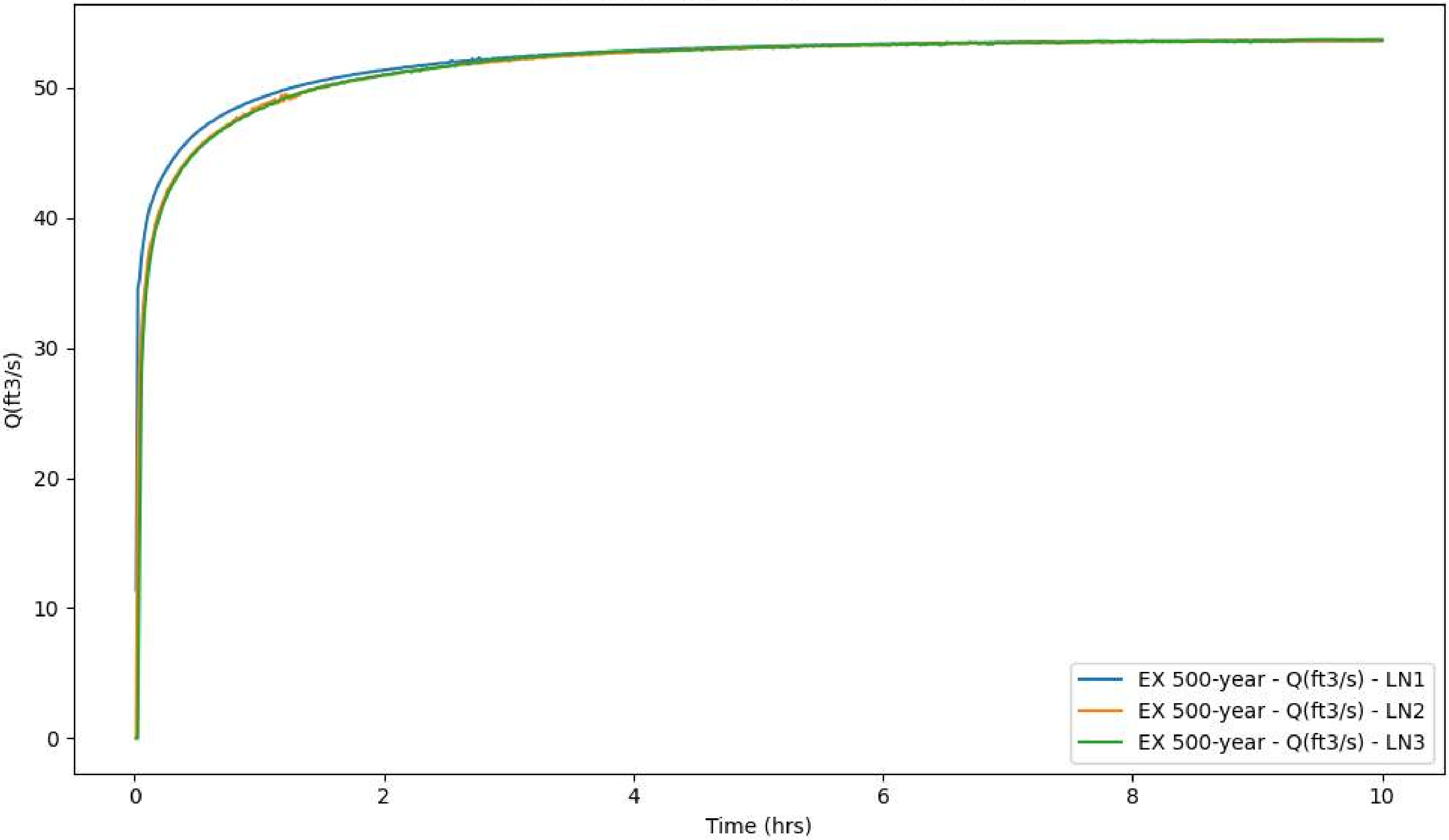
EXISTING CONDITIONS MONITOR LINE AND POINT LOCATIONS

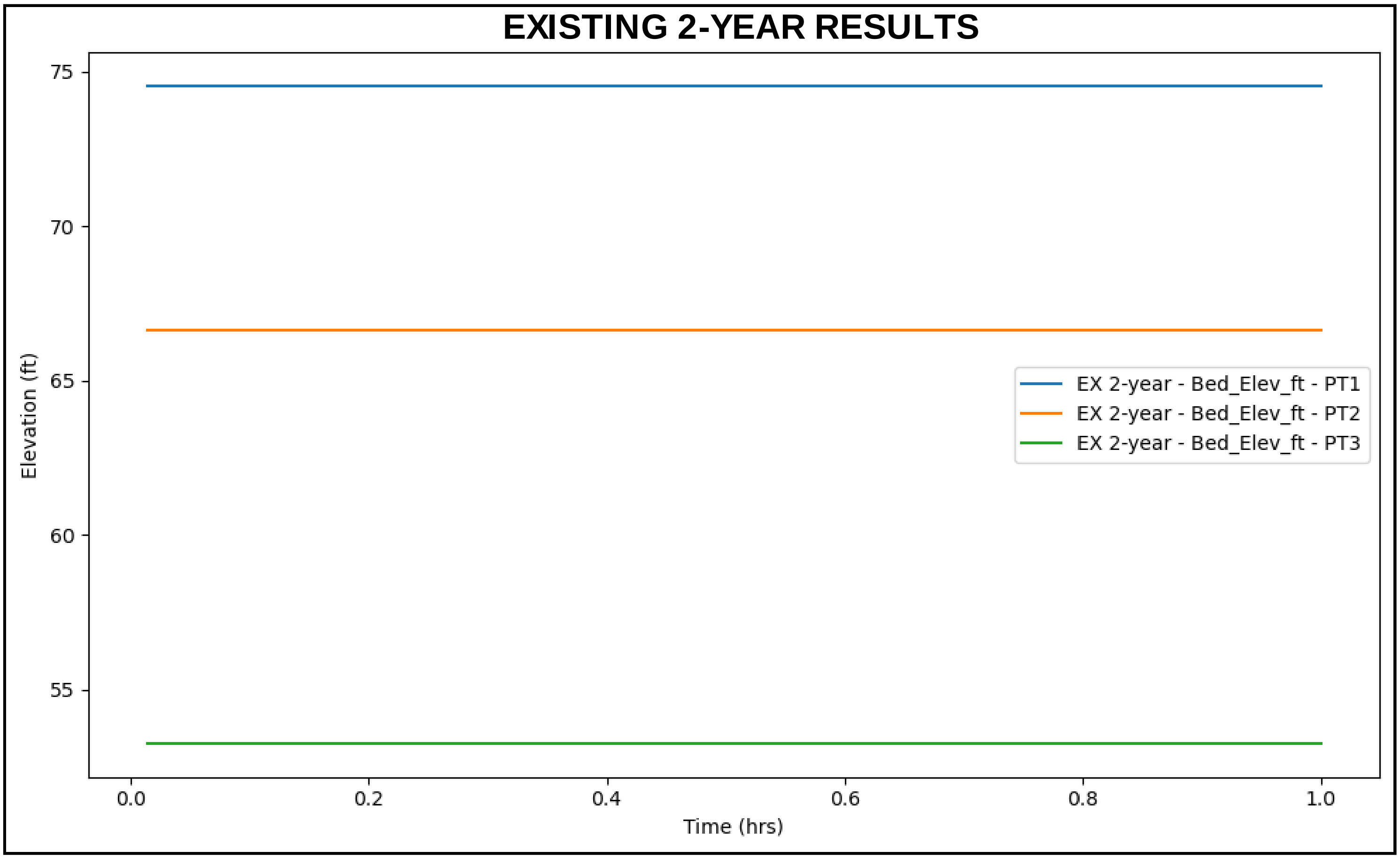


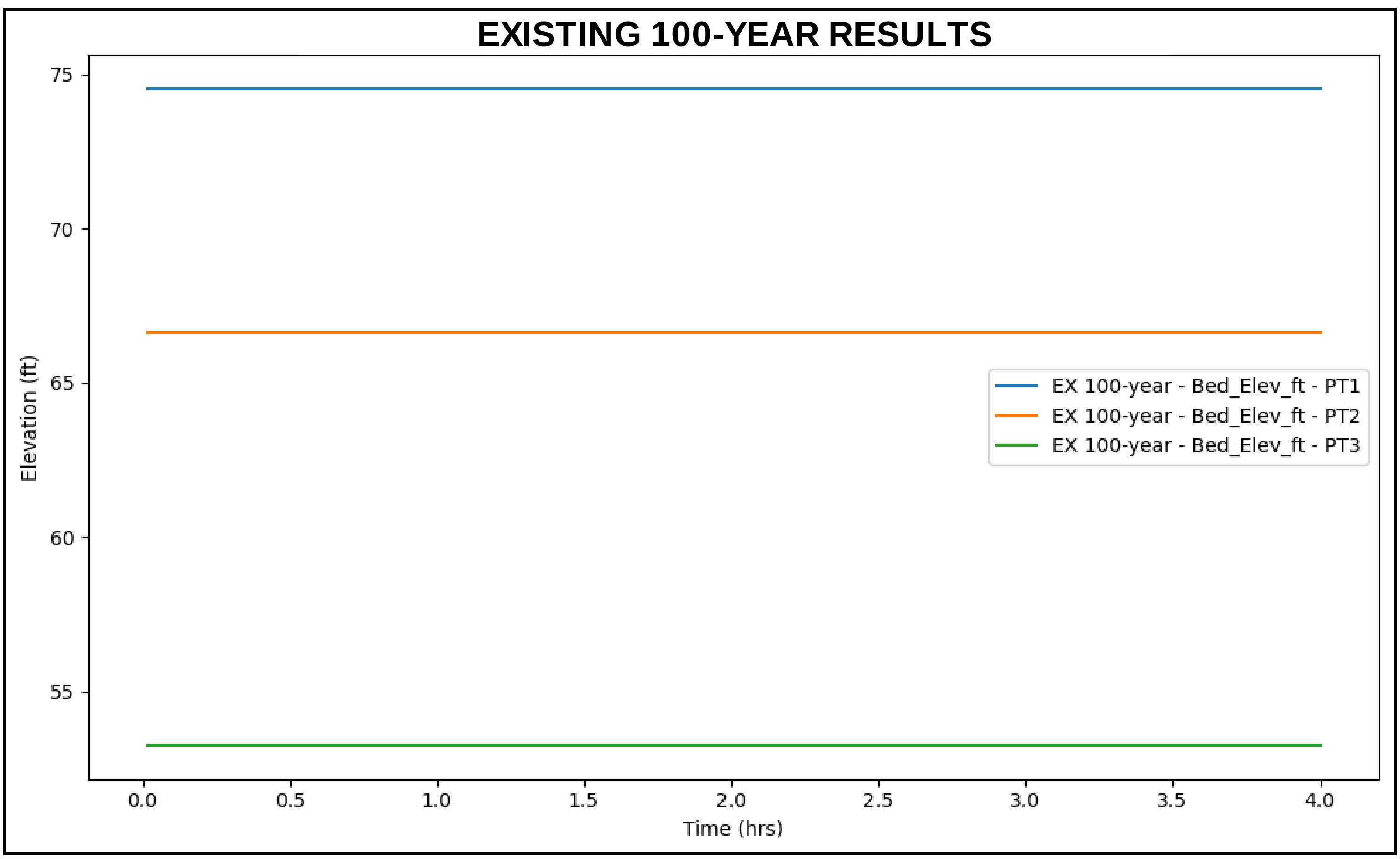

EXISTING 2-YEAR RESULTS
Q(ft3/s)
Time (hrs)
EX 2-year - Q(ft3/s) - LN1
EX 2-year - Q(ft3/s) - LN2
EX 2-year - Q(ft3/s) - LN3

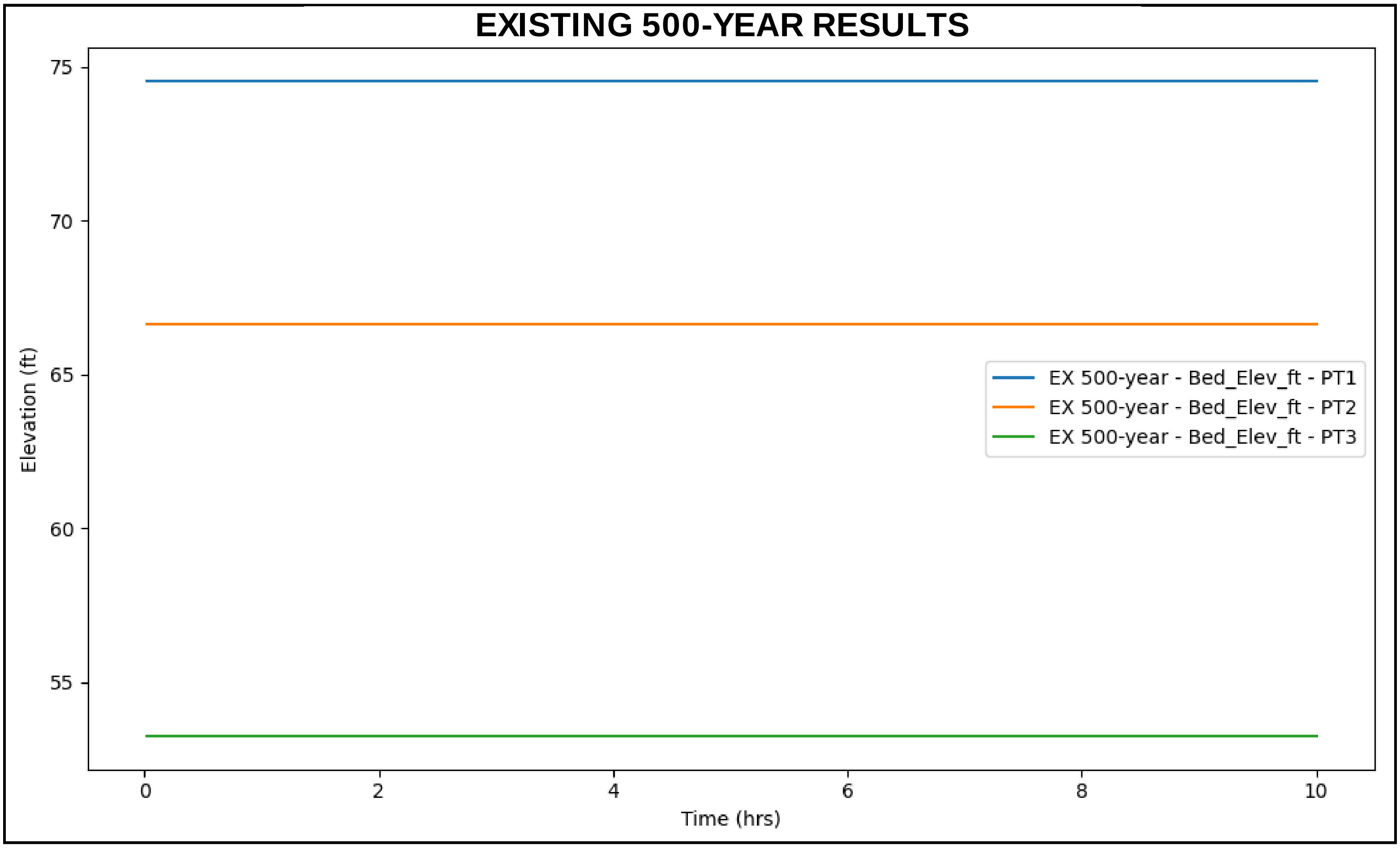

EXISTING 100-YEAR RESULTS
Q(ft3/s)
Time (hrs)
EX 100-year - Q(ft3/s) - LN1
EX 100-year - Q(ft3/s) - LN2
EX 100-year - Q(ft3/s) - LN3

EXISTING 500-YEAR RESULTS



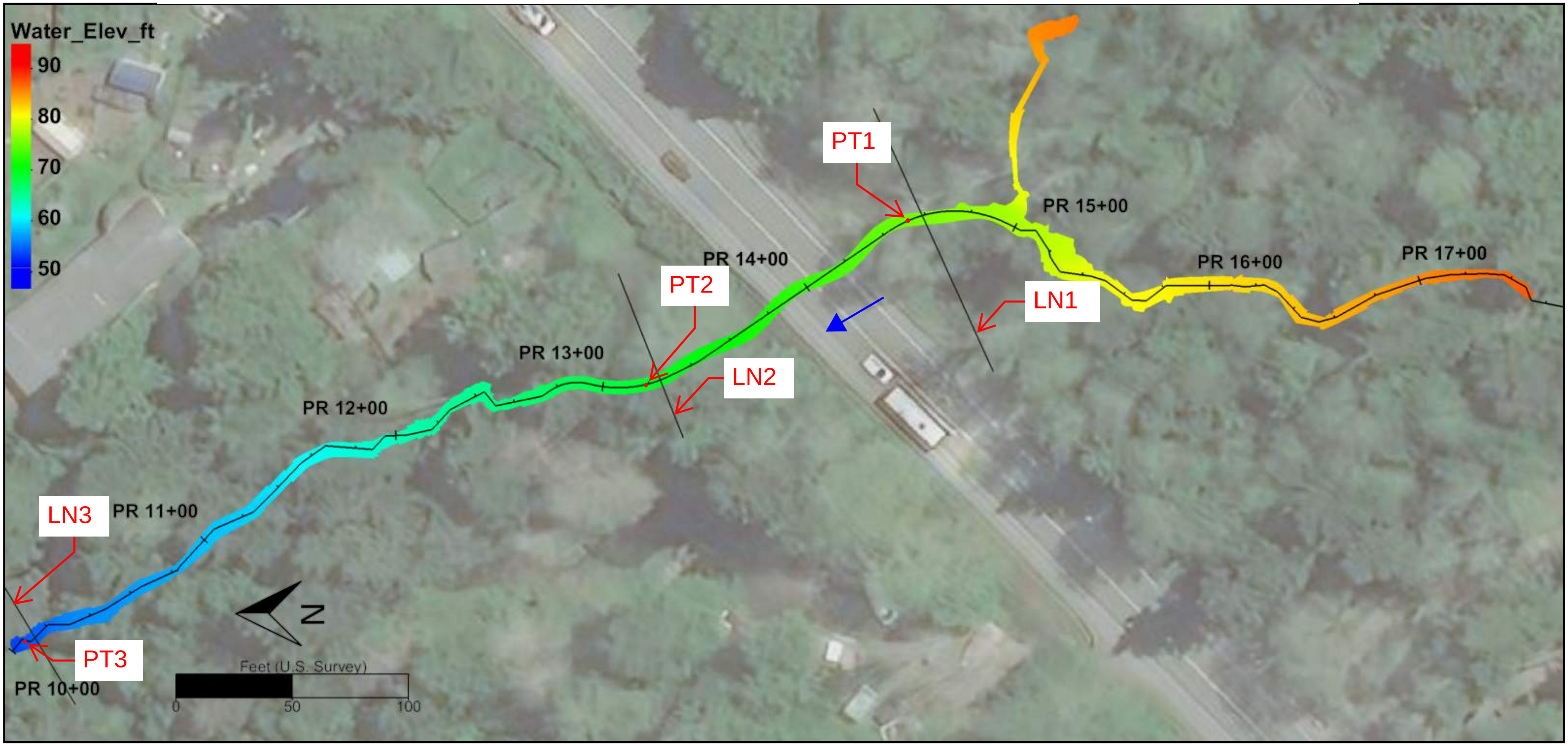

EXISTING 2-YEAR RESULTS
75
70
65
60
55
Elevation (ft)
0.0
0.2
0.4
0.6
0.8
1.0
Time (hrs)
EX 2-year - Bed_Elev_ft - PT1
EX 2-year - Bed_Elev_ft - PT2
EX 2-year - Bed_Elev_ft - PT3


EXISTING 100-YEAR RESULTS
75
70
65
60
55
Elevation (ft)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (hrs)
EX 100-year - Bed_Elev_ft - PT1
EX 100-year - Bed_Elev_ft - PT2
EX 100-year - Bed_Elev_ft - PT3

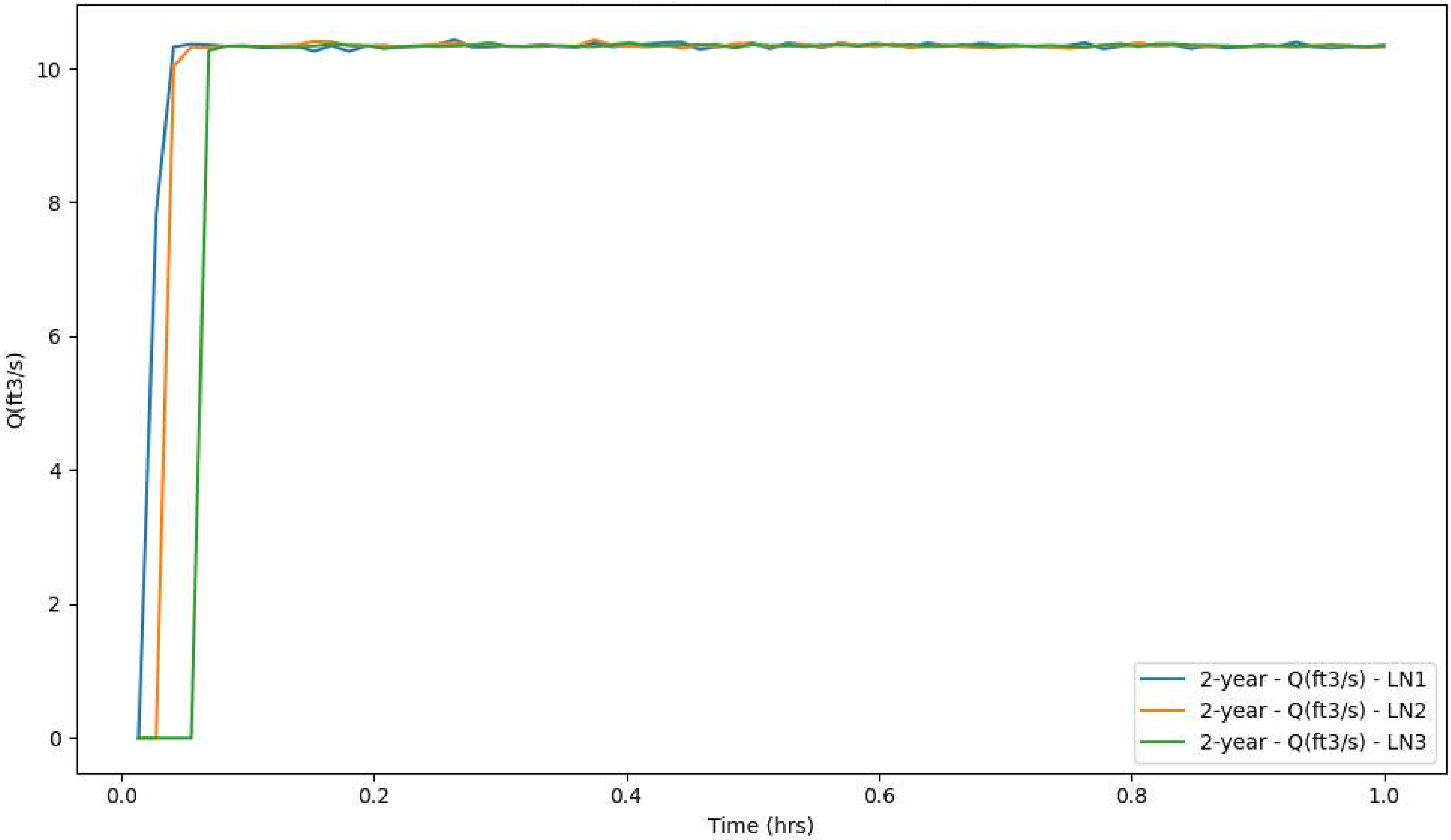


EXISTING 500-YEAR RESULTS
75
70
65
60
55
Elevation (ft)
0
2
4
6
8
10
Time (hrs)
EX 500-year - Bed_Elev_ft - PT1
EX 500-year - Bed_Elev_ft - PT2
EX 500-year - Bed_Elev_ft - PT3

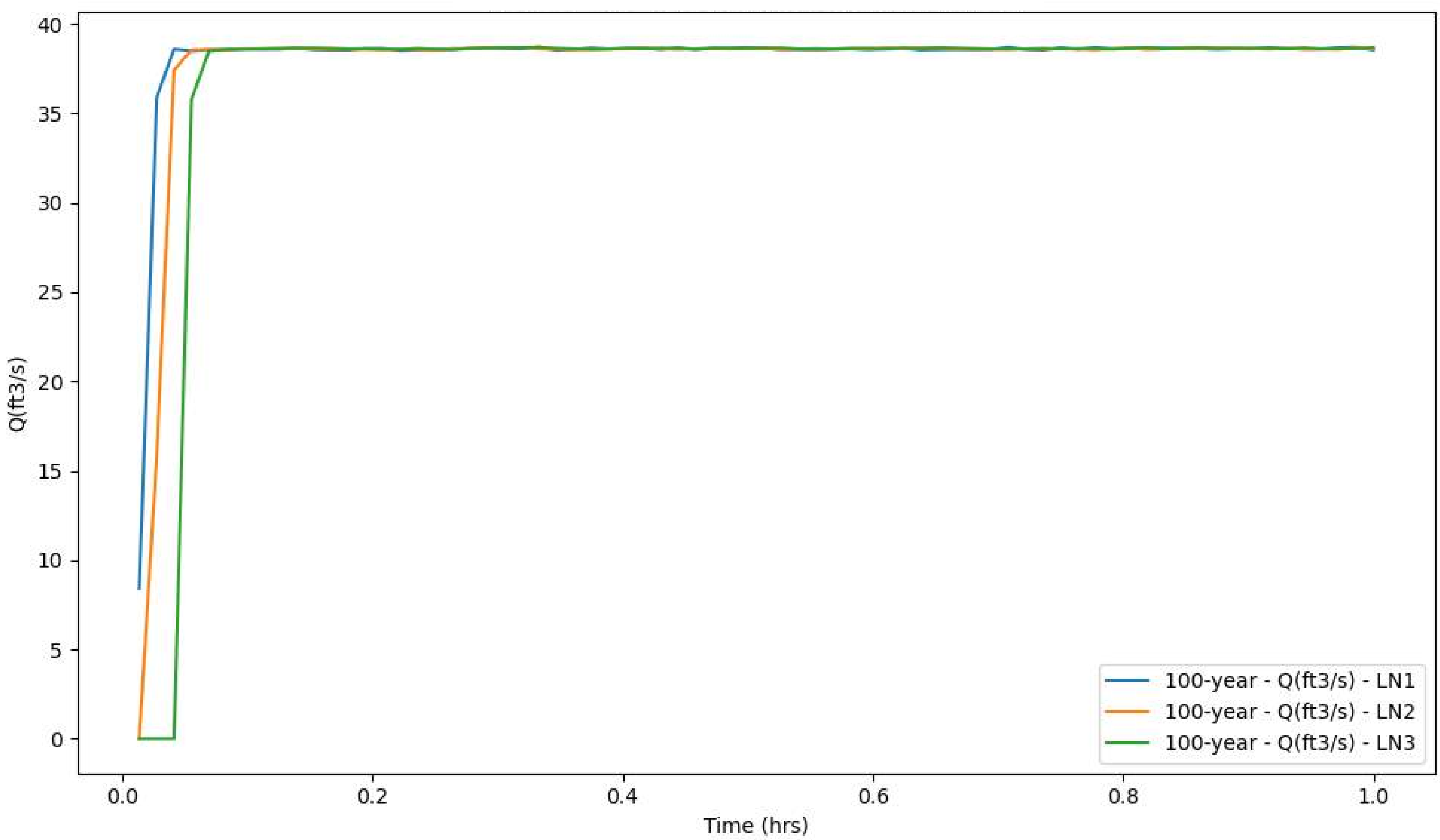
PROPOSED CONDITIONS MONITOR LINE AND POINT LOCATIONS



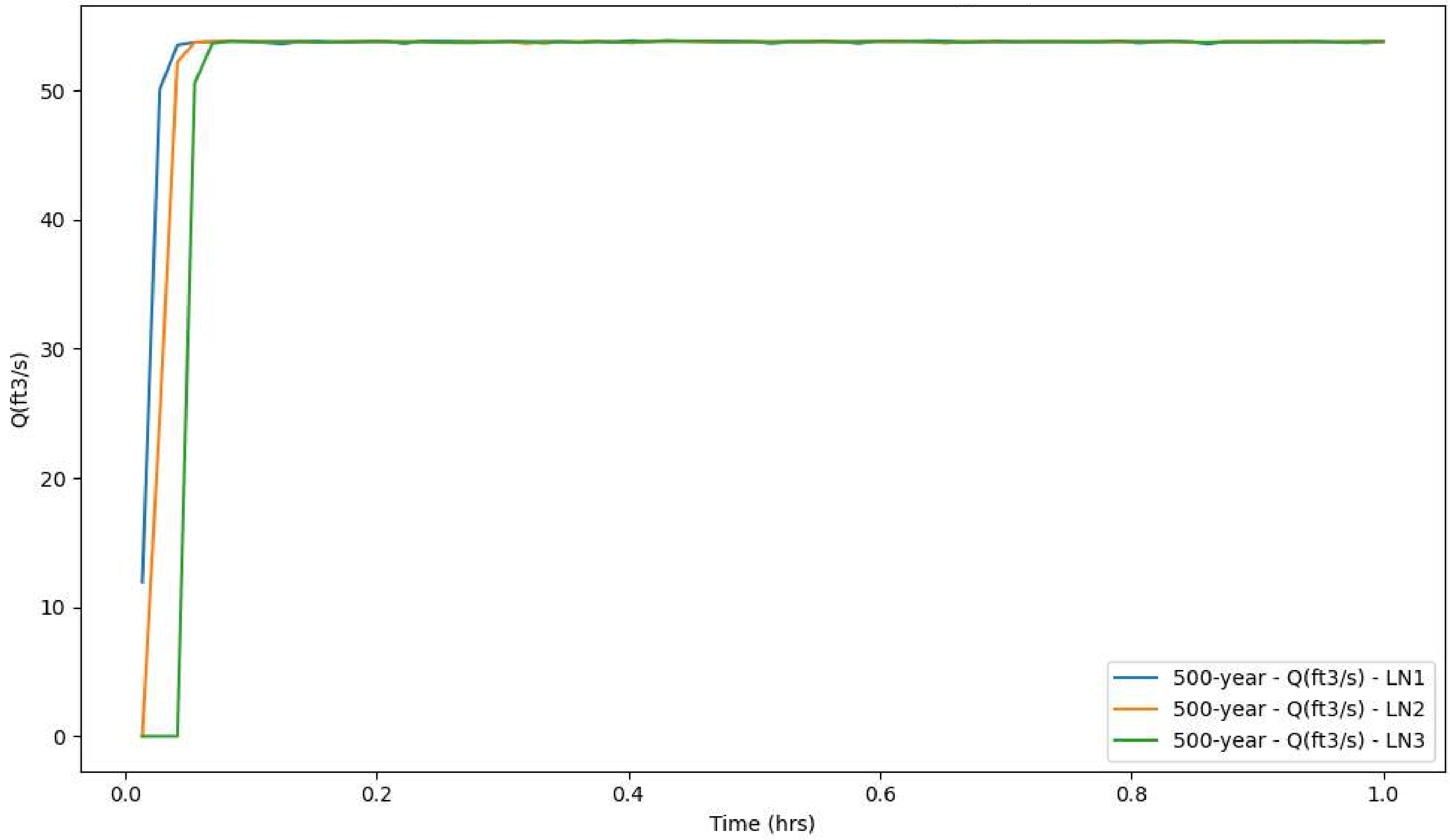
PROPOSED 2-YEAR RESULTS



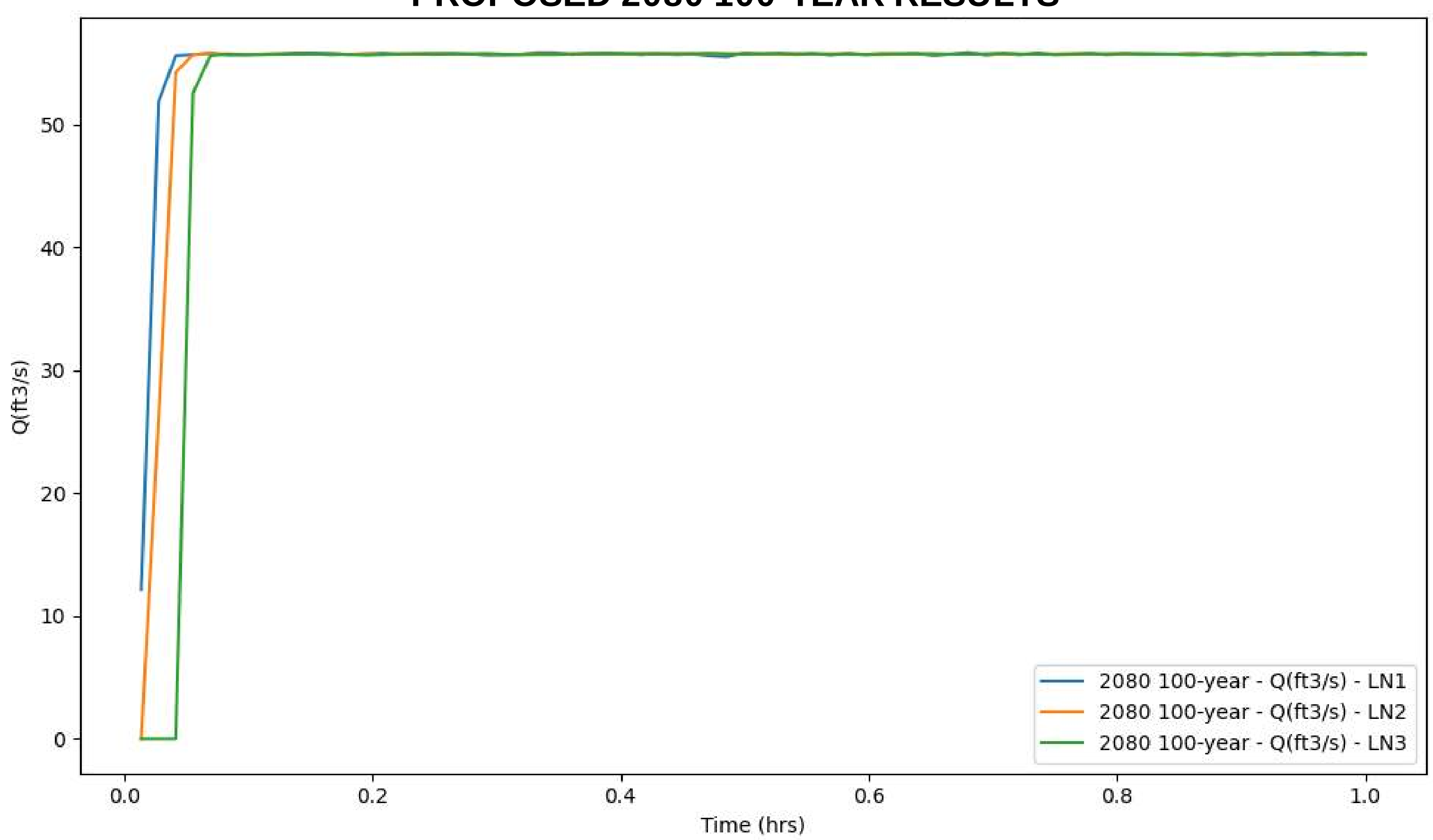
PROPOSED 100-YEAR RESULTS



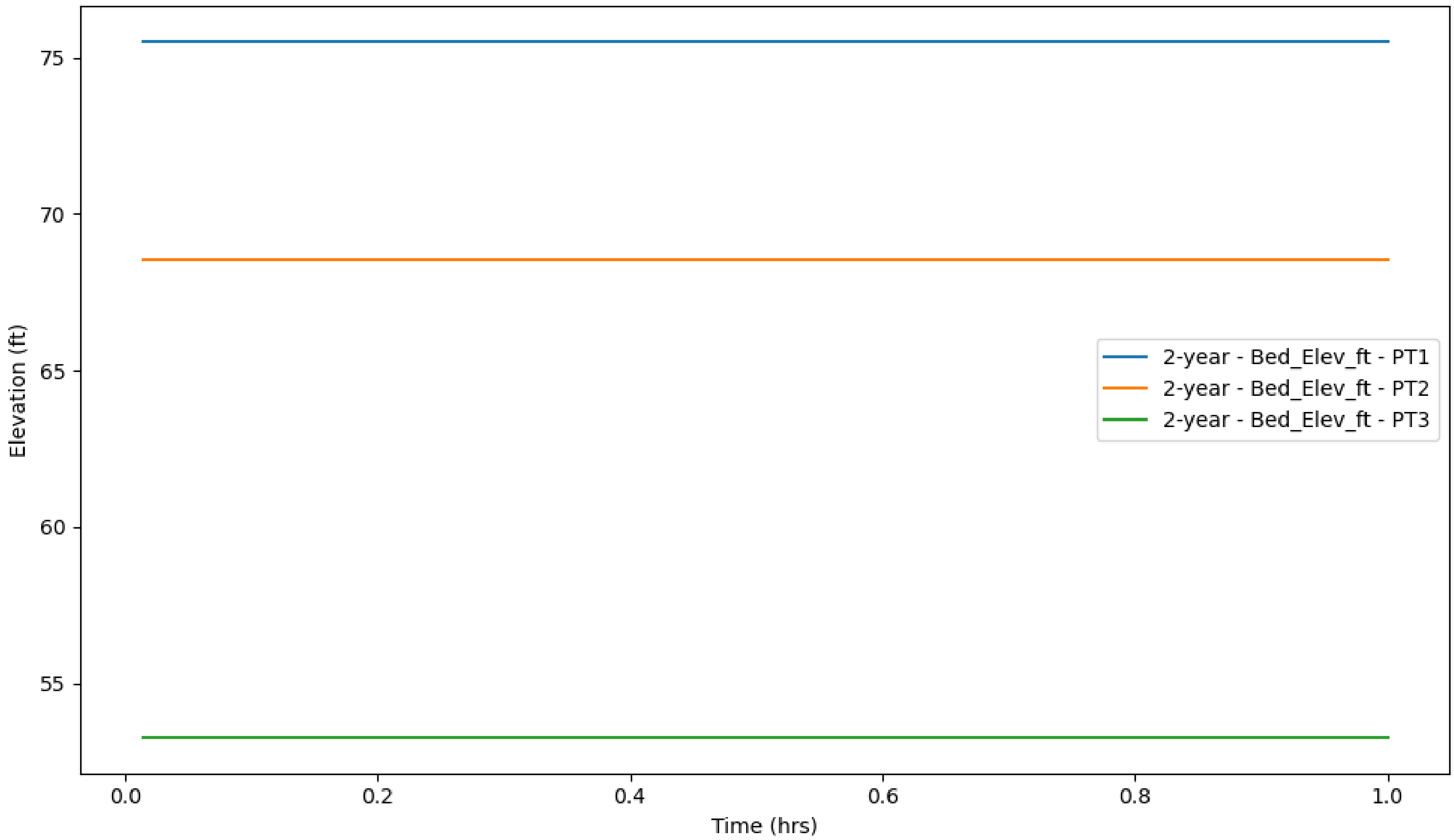
PROPOSED 500-YEAR RESULTS



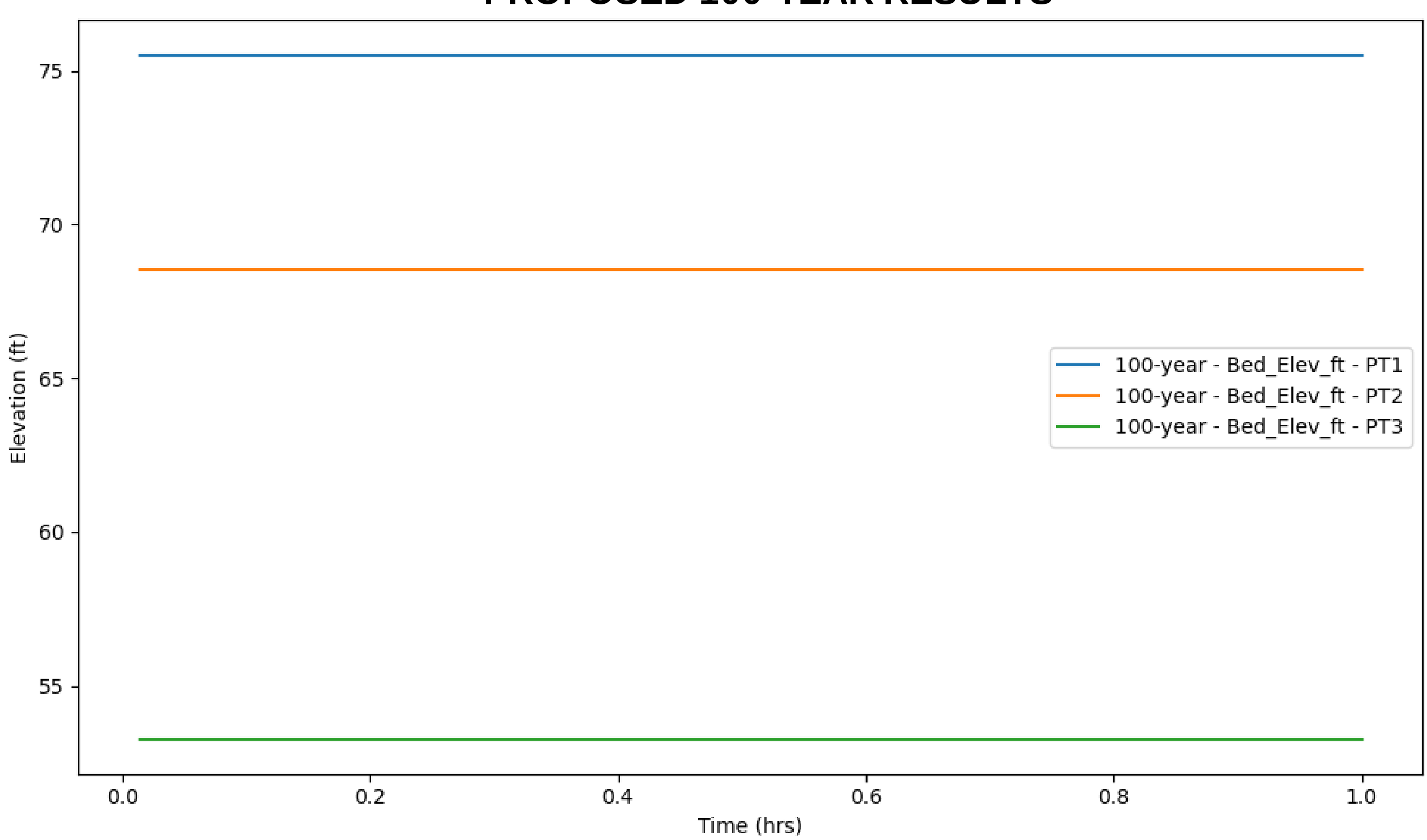
PROPOSED 2080 100-YEAR RESULTS

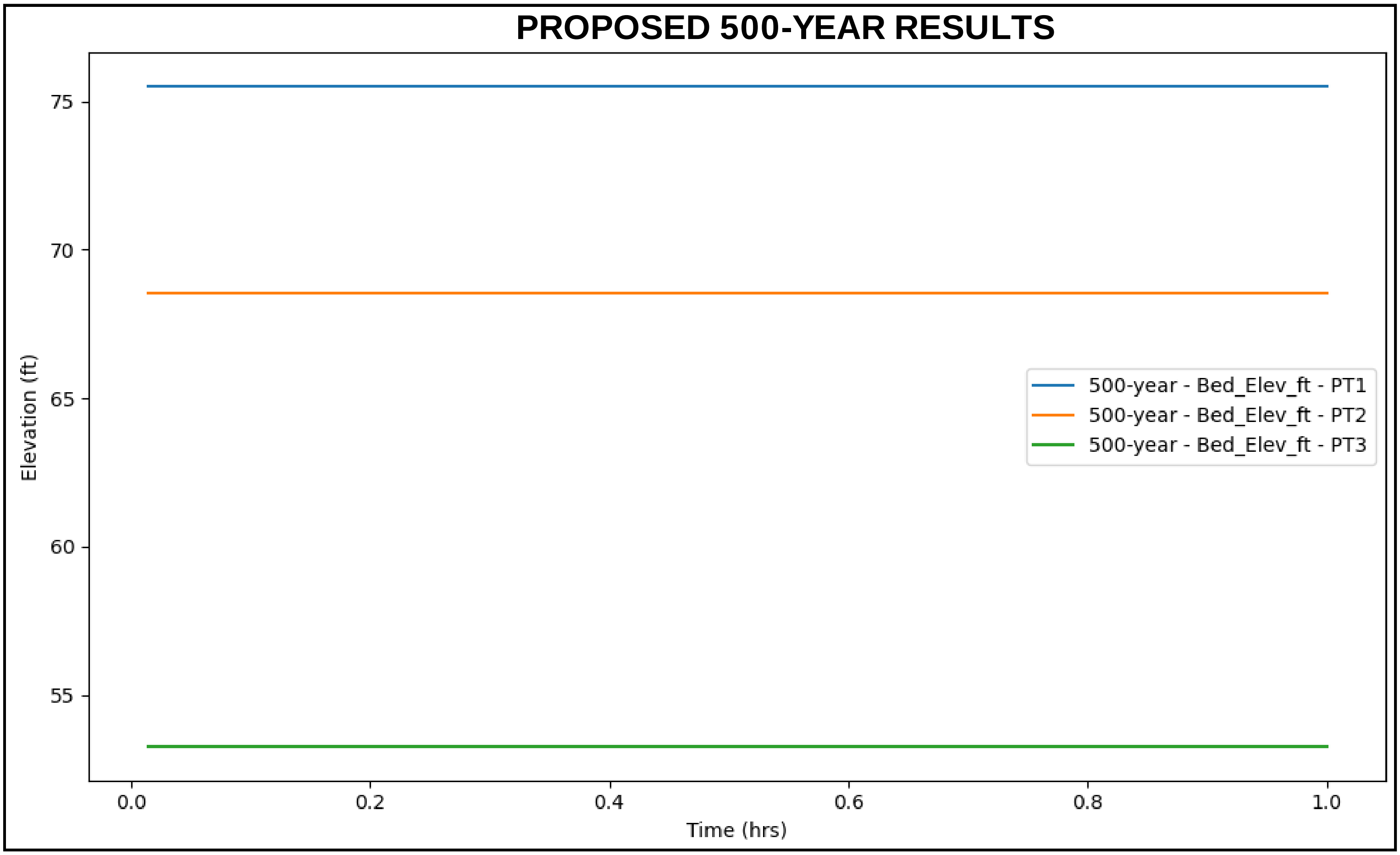


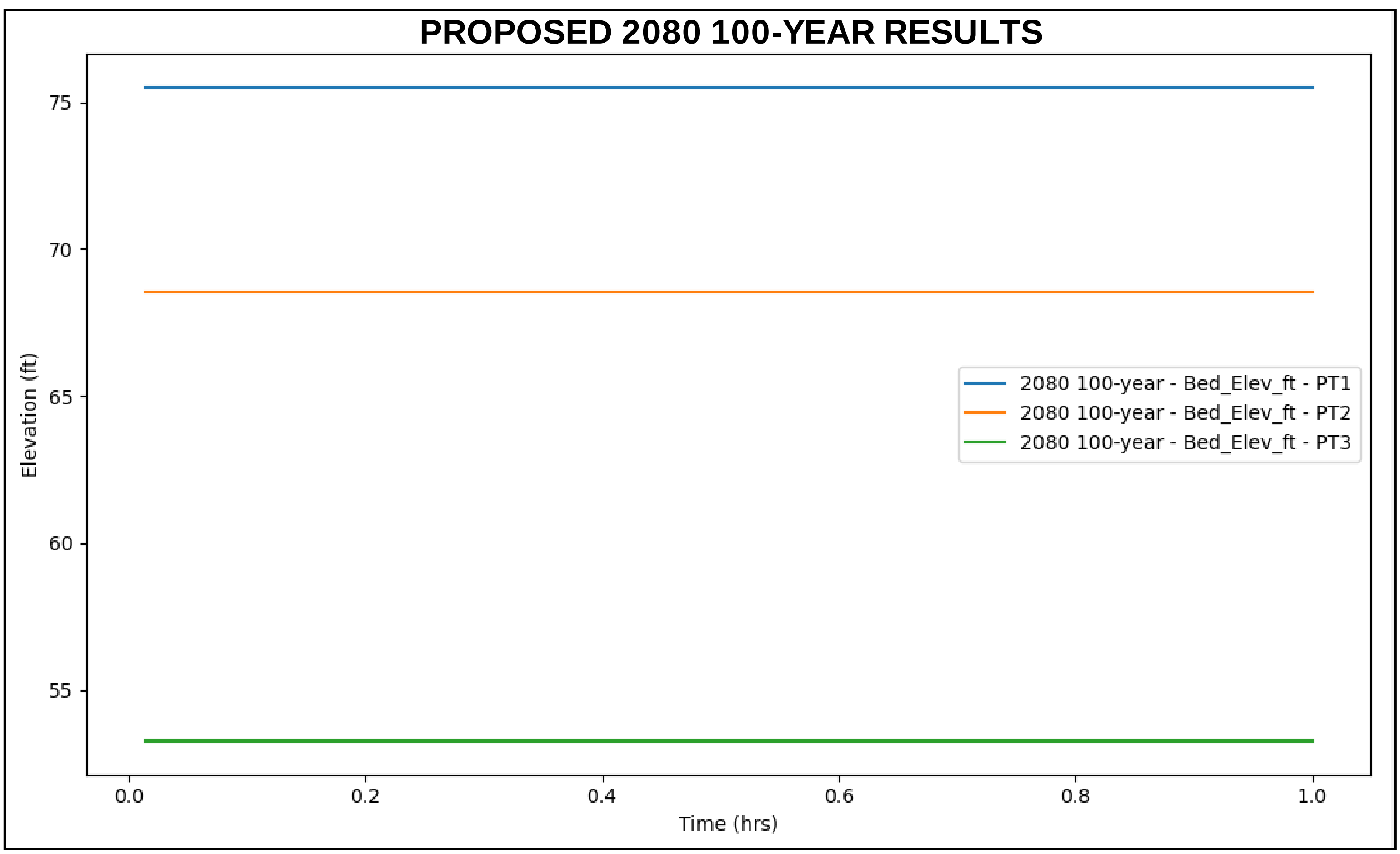
PROPOSED 2-YEAR RESULTS



PROPOSED 100-YEAR RESULTS




PROPOSED 500-YEAR RESULTS
Elevation (ft)
75
70
65
60
55
0.0
0.2
0.4
0.6
0.8
1.0
Time (hrs)
500-year - Bed_Elev_ft - PT1
500-year - Bed_Elev_ft - PT2
500-year - Bed_Elev_ft - PT3


PROPOSED 2080 100-YEAR RESULTS
Elevation (ft)
75
70
65
60
55
0.0
0.2
0.4
0.6
0.8
1.0
Time (hrs)
2080 100-year - Bed_Elev_ft - PT1
2080 100-year - Bed_Elev_ft - PT2
2080 100-year - Bed_Elev_ft - PT3

Appendix J: Reach Assessment

NOT APPLICABLE

DRAFT

Appendix K: Scour Calculations

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Figure 1. 2080 100-year velocity results with bridge scour arc locations.

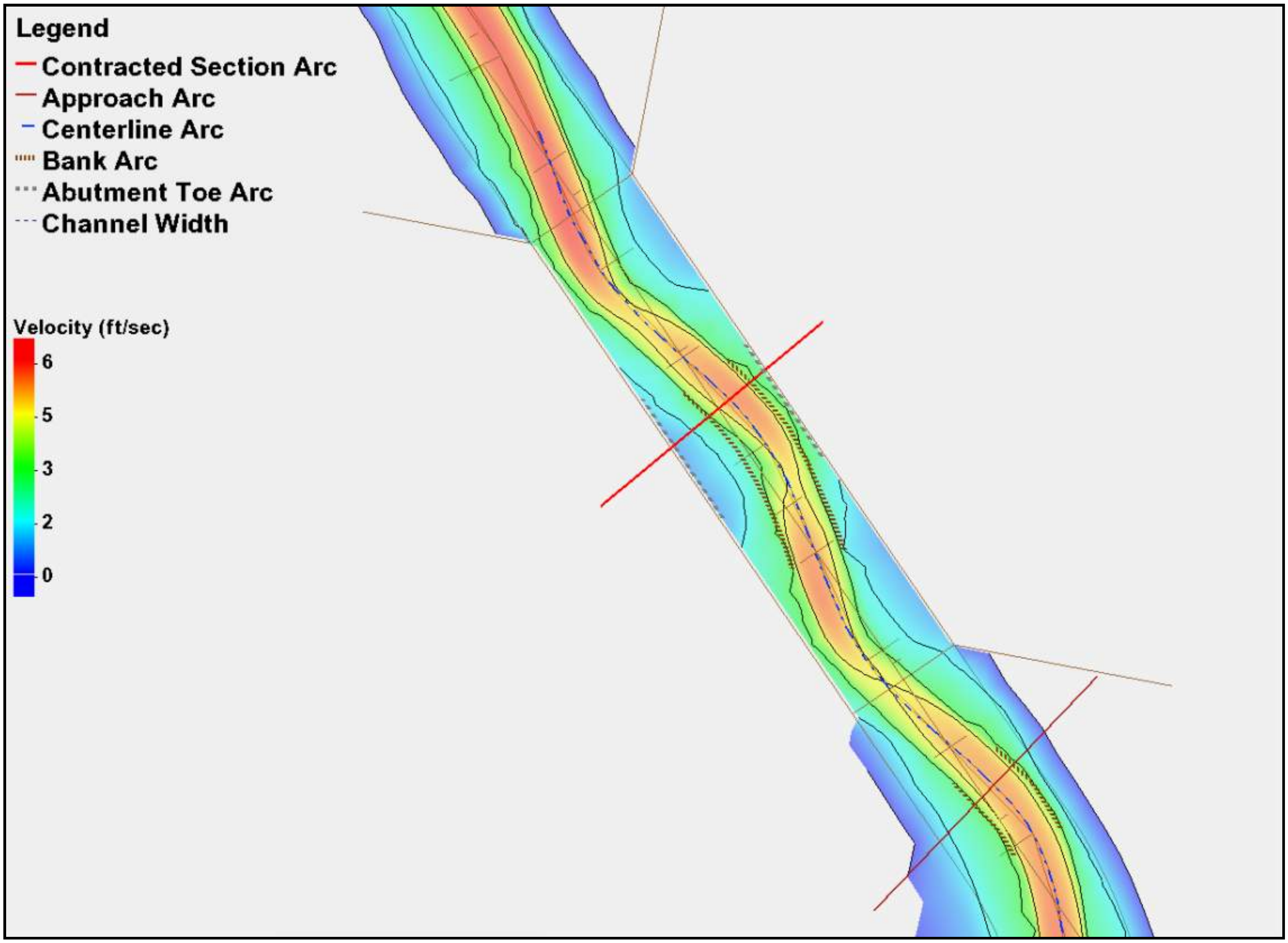

Figure 2. Bridge Scour Summary Table

Bridge Scour Summary Table

Parameter	Q2	Q25	Q100	Q500	Q2080 100	Units	Notes	Plot
Scenario	☐	☐	☐	☐	☑			
Bridge Geometry								☑
Bridge Cross-Section								☑
WSE	☑	☑	☑	☑	☑			☑
Contraction Scour	☐	☐	☐	☐	☑			☐
Clear Water Contraction Scour Depth	**-0.14**	-0.19	-0.20	-0.22	-0.22	ft	Clear-Water and Live-Bed Scour	
Live Bed Contraction Scour Depth	**0.00**	0.00	0.00	0.00	0.00	ft	Clear-Water and Live-Bed Scour	
Applied Contraction Scour Elevation with LTD	**70.64**	70.64	70.64	70.64	70.64	ft	Clear-Water and Live-Bed Scour	
Approach Cross-Section								☐
Local Scour at Abutments								
Left Abutment								☑
Plot Left Abutment Scour	☐	☐	☐	☐	☑			☐
Abutment Scour Depth	-0.17	-0.10	0.02	0.24	**0.27**	ft	NCHRP Method: Scour Condition A (in...	
Total Scour at Abutment	0.00	0.00	0.02	0.24	**0.27**	ft		
Total Scour Elevation at Abutment	70.51	70.41	70.28	70.05	**70.02**	ft		
Right Abutment								☑
Plot Right Abutment Scour	☐	☐	☐	☐	☑			☐
Abutment Scour Depth	-0.17	-0.10	0.02	0.24	**0.27**	ft	NCHRP Method: Scour Condition A (in...	
Total Scour at Abutment	0.00	0.00	0.02	0.24	**0.27**	ft		
Total Scour Elevation at Abutment	70.51	70.41	70.28	70.05	**70.02**	ft		

Figure 3. 2080 100-year Contraction Scour

Contraction Scour

Computation Method: Clear-Water and Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.43	ft	
D50	27.127200	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.79	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	5.30	ft/s	
Contraction Scour Condition	Clear Water		
Clear Water Input Parameters			
Discharge in Contracted Section	41.91	cfs	
Bottom Width in Contracted Section	5.77	ft	Width should exclude pier wi...
Depth Prior to Scour in Contracted Section	1.50	ft	
Live Bed & Clear Water Input Parameters			
Temperature of Water	60.00	ºF	
Slope of Energy Grade Line at Approach Section	0.044864	ft/ft	
Discharge in Contracted Section	41.91	cfs	
Discharge Upstream that is Transporting Sediment	40.63	cfs	
Width in Contracted Section	5.77	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	5.91	ft	
Depth Prior to Scour in Contracted Section	1.50	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the b...	33.909000	mm	
Average Depth in Contracted Section after Scour	1.27	ft	
Scour Depth	-0.22	ft	Negative values imply 'zero' ...
Results of Live Bed Method			
k1	0.640000		
Shear Velocity	1.44	ft/s	
Fall Velocity	1.64	ft/s	
Average Depth in Contracted Section after Scour	1.50	ft	
Scour Depth	0.00	ft	Negative values imply 'zero' ...
Shear Applied to Bed by Live-Bed Scour	0.3931	lb/ft^2	
Shear Required for Movement of D50 Particle	0.3561	lb/ft^2	
Recommendations			
Recommended Scour Depth	-0.22	ft	Negative values imply 'zero' ...

Figure 4. 2080 100-year Left Abutment Scour

Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	6.87	cfs/ft	
Unit Discharge in Constricted Area (q2)	7.25	cfs/ft	
D50	27.127200	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.43	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.78	ft	Depth at Abutment Toe
Results			
q2 / q1	1.05		
Average Velocity Upstream	4.79	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	5.30	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.49		
Flow Depth including Contraction Scour	1.38	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	2.05	ft	Including the long-term scour de...
Scour Hole Depth	0.27	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	0.28	ft	

Figure 5. 2080 100-year Right Abutment Scour

Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	6.87	cfs/ft	
Unit Discharge in Constricted Area (q2)	7.25	cfs/ft	
D50	27.127200	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.43	ft	
Define Shear Stress of Floodplain			
Flow Depth prior to Scour	1.78	ft	Depth at Abutment Toe
Results			
q2 / q1	1.05		
Average Velocity Upstream	4.79	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	5.30	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.49		
Flow Depth including Contraction Scour	1.38	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	2.05	ft	Including the long-term scour de...
Scour Hole Depth	$\boxed{0.27}$	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	0.28	ft	

Appendix L: Floodplain Analysis *(FHD ONLY)*

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Appendix M: Scour Countermeasure Calculations (FHD ONLY)

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